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THE STRIPED BASS PARTY BOAT FISHERY: 1960–1968[1]

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Striped bass (*Morone saxatilis*) full-day party boat records are analyzed and compared with earlier trends in the fishery. Angler success reached an all-time high for north San Francisco Bay during the 1960–63 period and then began to decline. Success in the other major areas generally declined throughout the study period. The average size of bass in the catch increased markedly. The data strongly suggest a decline in numbers of bass, although the biomass caught per angler day has remained relatively stable during the period of decline.

INTRODUCTION

This report is a continuation of reports previously published on the catch of the striped bass (*Morone saxatilis*) party boat fishery. Calhoun (1949) published an analysis of party boat records for the years 1938 to 1948, and Chadwick (1962) analyzed records from 1949 through 1959. This report includes the years 1960 through 1968.

Party boat operators are required by law to keep a log of each trip made, although past studies have indicated that some trips are not reported (Johnson, 1951; Chadwick, 1962). These reports are submitted monthly to the California Department of Fish and Game on forms supplied to the operators by the Department. The form used in northern California during most of the current period is shown in Figure 1.

Boat Name

Fish and Game No.

Town of Landing

Skipper: Please make a separate log for each trip of the day.

FG 623. DUP ⓘ △F ⓑ SPO

KIND OF FISH CAUGHT	NUMBER	AVERAGE WT.
ROCKFISH (Cod)		
LINGCOD		
CABEZON		
SALMON		
STRIPED BASS		
MACKEREL (Pacific)		
MACKEREL (Jack)		
HALIBUT		
OTHER FLATFISH		
NAME OTHER FISH		

Month Day Year

No. of Hours Fished (Hours Lines in Water)

Number of Anglers

Block Number Where Most Fish Caught

№ 13251

FIGURE 1. Daily log form used for party boat reports.

[1] Accepted for publication May 1970. This work was performed as part of Dingell-Johnson Projects California F-9-R, "A Study of Sturgeon and Striped Bass" supported by Federal Aid to Fish Restoration Funds.
[2] Present address, 3900 North Wilson Way, Stockton, California 95205.

GENERAL DISCUSSION OF PARTY BOAT OPERATIONS

The striped bass party boat fishery is concentrated in San Francisco and San Pablo Bays and Carquinez Strait. It also operates in the Pacific Ocean, Suisun Bay, and Sacramento-San Joaquin Delta, though at a much lower level. The catch records are tabulated by the inland blocks delineated in Figure 2 and the ocean. Chadwick (1962) and Calhoun (1949) give detailed descriptions of the inland areas and the fishery.

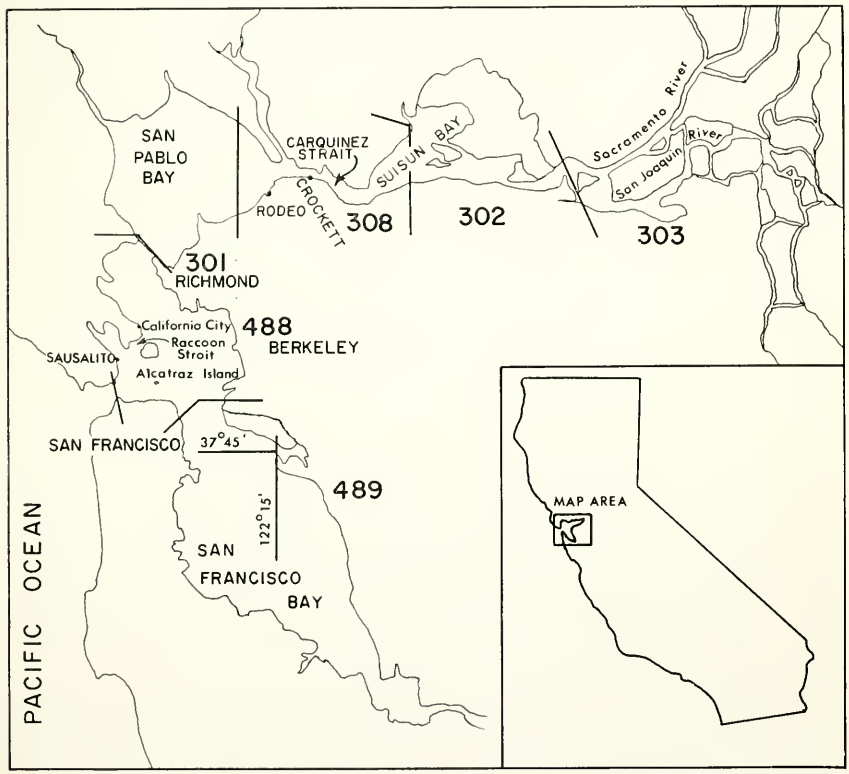

FIGURE 2. Map of California striped bass party boat fishing areas. The numbers indicate the fishing blocks referred to in the text.

The party boats are placed in one of four categories determined by the time spent fishing on a trip. By far the most prevalent are the full-day boats which average 75% of the effort (reported angler hours) each year. Full-day boats are those boats fishing during the morning and afternoon for more than 4.5 hr or boats on which everyone took limits. Other boats fishing during the morning or afternoon are termed half-day boats. These account for an average of 23% of the effort and often make two trips a day. The other categories are one and one-half day boats and boats which offer evening trolling. They contribute the remaining 2% of the total effort recorded. Only records from full-day boats are included here.

The migratory nature of the striped bass makes the fishery a seasonal one. Some fish are available in the lower bays all year and a number of boats operate continuously, but many boats fish only during peak seasons.

The 1960–1968 mean number of operators reporting declined 28% from the 1949–1959 mean. The mean reported full-day boat angler days is up 13% over the 1949–1959 mean (Table 1). These statistics reflect the recent trend to larger but fewer boats in the fishery.

TABLE 1—**Party Boat Fishing Effort and Catch 1960–1968**

Year	Number of* operators reporting	Angler days reported on full-day boats for inland blocks	Total bass caught from full-day boats in inland blocks	Full-day boat catch per angler day for all inland blocks
1938–48 mean	--	13,650		
1949–59 mean	132	15,625		
1960	105 (7)	19,826	38,597	1.95
1961	105 (5)	21,663	45,087	2.08
1962	106 (5)	19,325	39,728	2.05
1963	99 (18)	24,309	48,435	1.99
1964	87 (18)	15,480	21,397	1.38
1965	81 (26)	12,245	11,363	0.93
1966	81 (25)	17,802	23,259	1.31
1967	81 (12)	14,203	15,331	1.08
1968	84 (8)	13,581	14,977	1.10
1960–68 mean	95 (15)	17,603	28,686	

* Number of operators making one or more fishing trip in inland blocks. Figures in parentheses are operators reporting only ocean trips. Full-day, half-day, evening troll and 1.5-day boats are all included.

Limited evaluations of the usefulness of party boat reports were conducted by Chadwick (1962). He concluded that the reports provided a reliable index of fishing success, but they failed to provide adequate information on the striped bass population because all segments of the fishery were not covered and reliable information on the size composition of the catch was not available.

A problem developed in 1964 when the party boats operating in Blocks 301 and 308 (Figure 2) began enjoying some success catching sturgeon. This fishery rapidly gained in popularity and soon many of the party boats were devoting major portions of their effort toward sturgeon. This had the effect of increasing the effort recorded in these areas without the expected increase in catch of striped bass. To compensate for this, all effort expended on boat trips where sturgeon were caught was subtracted from the total party boat effort. Inherent deficiencies in this method of correction are: (i) sturgeon may be caught incidental to striped bass and vice versa; (ii) information on effort expended for sturgeon when no sturgeon were caught is not available. At the present time, there is no way of assessing either of these defects.

BLOCK RECORDS

Block 308—The Carquinez Strait Region

This area includes Carquinez Strait, the eastern quarter of San Pablo Bay, and a small portion of Suisun Bay (Figure 2).

Full-day party boat fishing effort dropped from a mean of 4,939 days per year for the 1949–59 period to 1,654 days from 1960–68. From 1960 to 1965 it remained relatively constant. Since 1965 effort has increased. This increase is probably partly due to including unsuccessful sturgeon trips.

Angler success as measured by catch per hour has been declining steadily since 1954 (Figure 3). The reported mean weight increased from a 1960–63 average of 5.0 lb. to a 1964–68 average of 9.5 lb. (Table 2, Figure 4). The most significant changes in weight occurred in 1963 and 1965. The mean weight has declined since the 1965 high of 12.1 lb. The mean weight reported for full-day boats is based on fewer fish in recent years. Mean weights from half-day boats from 1964–1968 were 9.5, 6.7, 7.3, and 5.7 respectively. Except for 1964 these means are based on larger samples than the full-day boat means.

TABLE 2—Summary of Full-Day Party Boat Reports from Carquinez Strait, Block 308

	Angler days		Striped bass				
Year	Number	Percentage of annual inland total	Number*	Percentage of annual inland total	Catch/ angler day	Catch/ angler hour	Mean weight
1938–48 mean	5,357	39	13,298	47	----	----	4.6
1949–59 mean	4,939	32	8,671	35	----	----	4.0
1960	1,189	6	1,467	4	1.23	0.16	6.0
1961	1,224	6	1,423	3	1.16	0.16	4.2
1962	1,117	6	1,337	3	1.20	0.16	3.8
1963	1,058	4	656	1	0.62	0.09	5.9
1964	1,024	7	866 (140)	4	0.85	0.12	8.0
1965	1,375	11	503 (358)	4	0.37	0.05	12.1
1966	2,611	15	1,228 (317)	5	0.47	0.07	10.1
1967	2,201	15	332 (166)	2	0.15	0.02	9.4
1968	3,092	23	836 (361)	6	0.27	0.04	8.0
1960–68 mean	1,654	10	961	4	----	----	7.5

* Figures in parentheses are the numbers of additional bass caught along with sturgeon on full-day boats (mean weights are based on combined figures).

Catches per hour for months where 30 or more trips were made are shown in Figure 5. The effort in this block was too sparse to draw any conclusions about seasonal trends.

Block 301—San Pablo Bay

Effort in this area has declined since the peak period from 1958–60. However, the 1960–68 mean angler days reported for the area are above the 1949–59 average. Historically, effort in this area has fluctuated greatly. As in Block 308, effort increased here in 1965 and 1966 but declined since then.

Catch per hour declined steadily over the years of this report (Figure 3). Reported mean weights increased considerably from 4.6 in 1960 to 12.6 in 1965 (Table 3, Figure 4). The 1968 mean dropped to 9.4 lbs. As in Block 308, the mean weights reported from half-day boats from 1964–68 are lower than those from full day boats. Half-day

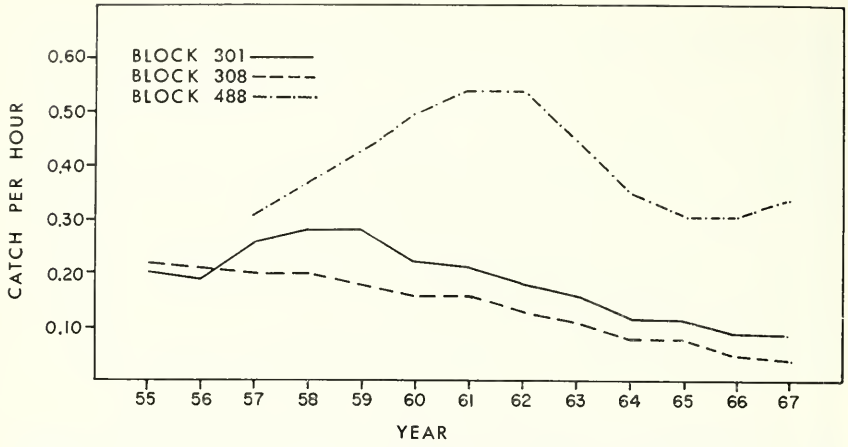

FIGURE 3. Three-year moving average of mean annual catch per hour of striped bass caught on full-day party boats fishing in Blocks 301, 308 and 488 (1955–1959 data from Chadwick, 1962).

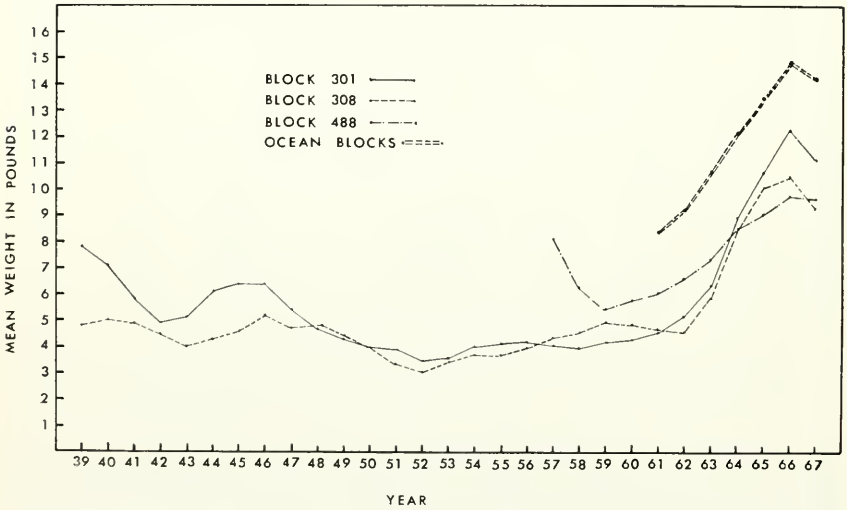

FIGURE 4. Three-year moving average of mean annual weights of striped bass caught on full-day party boats fishing in Blocks 301, 308, 488 and the Pacific Ocean (1939–1959 data from Chadwick, 1962).

mean weights from 1964–68 are 5.3, 7.9, 9.4, 7.8 and 7.7. These means are based on about the same sample size recorded for full-day boats.

Seasonal trends in angler success (Figure 6) point to an increasingly well defined season in this block, running from September through April. The summer and fall fisheries are similar to those prior to 1959 (Chadwick, 1962), but the November through February effort increased considerably during the current period. This winter effort corresponds to the peak of the sturgeon fishery and a portion of the effort is probably unsuccessful sturgeon effort.

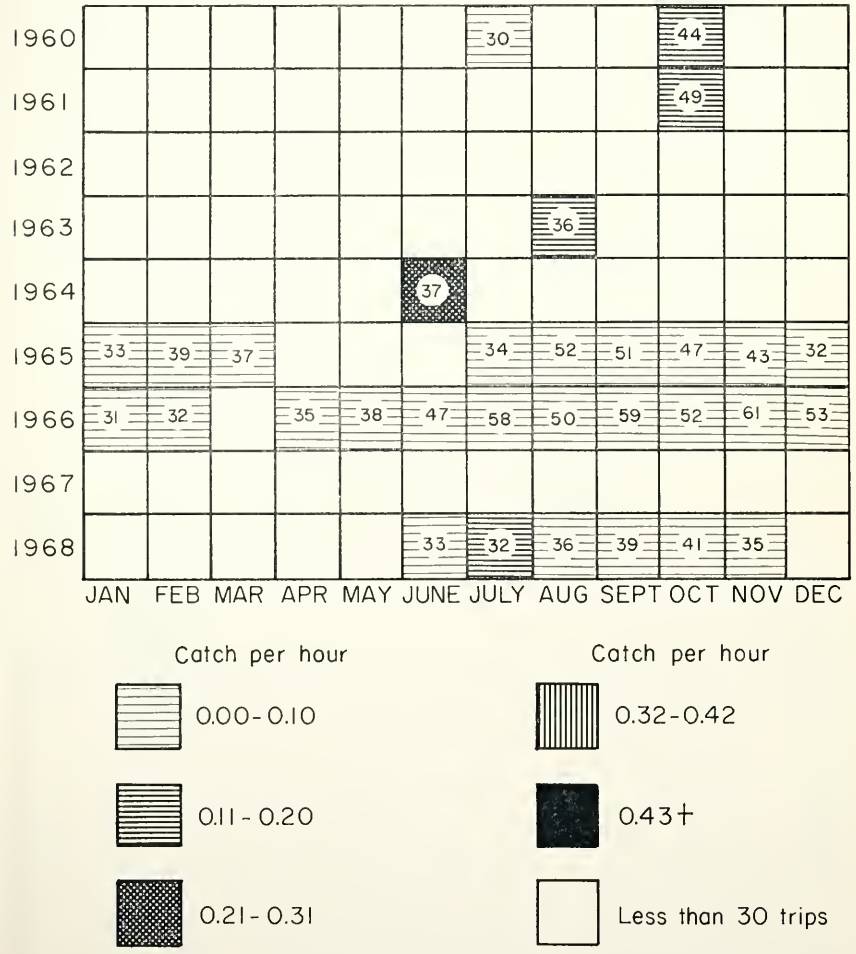

FIGURE 5. Monthly catches per unit of effort for striped bass by anglers fishing from full-day party boats in Block 308 (numbers in squares are the numbers of trips in that month).

TABLE 3—**Summary of Full-Day Party Boat Reports from San Pablo Bay, Block 301**

	Angler days		Striped bass				
Year	Number	Percentage of annual inland total	Number*	Percentage of annual inland total	Catch/ angler day	Catch/ angler hour	Mean weight
1938–48 mean	3,803	28	7,156	25	----	----	6.2
1949–59 mean	3,338	21	6,288	25	----	----	3.9
1960	7,101	36	11,391	30	1.60	0.23	4.6
1961	6,396	29	9,381	21	1.47	0.21	4.3
1962	5,173	27	7,528	19	1.46	0.20	4.8
1963	3,596	15	3,511	7	0.98	0.14	6.6
1964	3,780	24	3,474 (96)	16	0.92	0.13	7.8
1965	4,398	36	2,937 (242)	26	0.67	0.10	12.6
1966	4,655	26	4,091 (423)	18	0.88	0.13	11.8
1967	3,096	22	917 (782)	6	0.30	0.04	12.5
1968	3,313	24	2,213 (413)	15	0.67	0.10	9.4
1960–68 mean	4,612	27	5,049	18	----	----	8.3

* Figures in parentheses are the numbers of additional bass caught along with sturgeon on full-day boats (mean weights are based on combined figures).

TABLE 4—**Summary of Full-Day Party Boat Reports from Upper San Francisco Bay, Block 488**

	Angler days		Striped bass				
Year	Number	Percentage of annual inland total	Number	Percentage of annual inland total	Catch/ angler day	Catch/ angler hour	Mean weight
1938–48 mean	1,195	9	2,048	7	----	----	6.5
1949–59 mean	2,559	16	4,693	19	----	----	----
1960	10,566	53	24,633	64	2.33	0.49	6.0
1961	12,933	60	32,469	72	2.51	0.59	5.9
1962	12,147	63	29,471	74	2.43	0.55	6.4
1963	19,172	79	43,776	90	2.28	0.49	7.5
1964	10,079	65	16,666	78	1.65	0.32	8.3
1965	5,718	47	7,234	64	1.27	0.22	9.9
1966	9,264	52	17,016	73	1.85	0.38	9.4
1967	7,816	55	12,696	83	1.62	0.31	10.0
1968	6,629	49	11,549	77	1.74	0.34	9.8
1960–68 mean	10,480	58	21,733	75	----	----	8.1

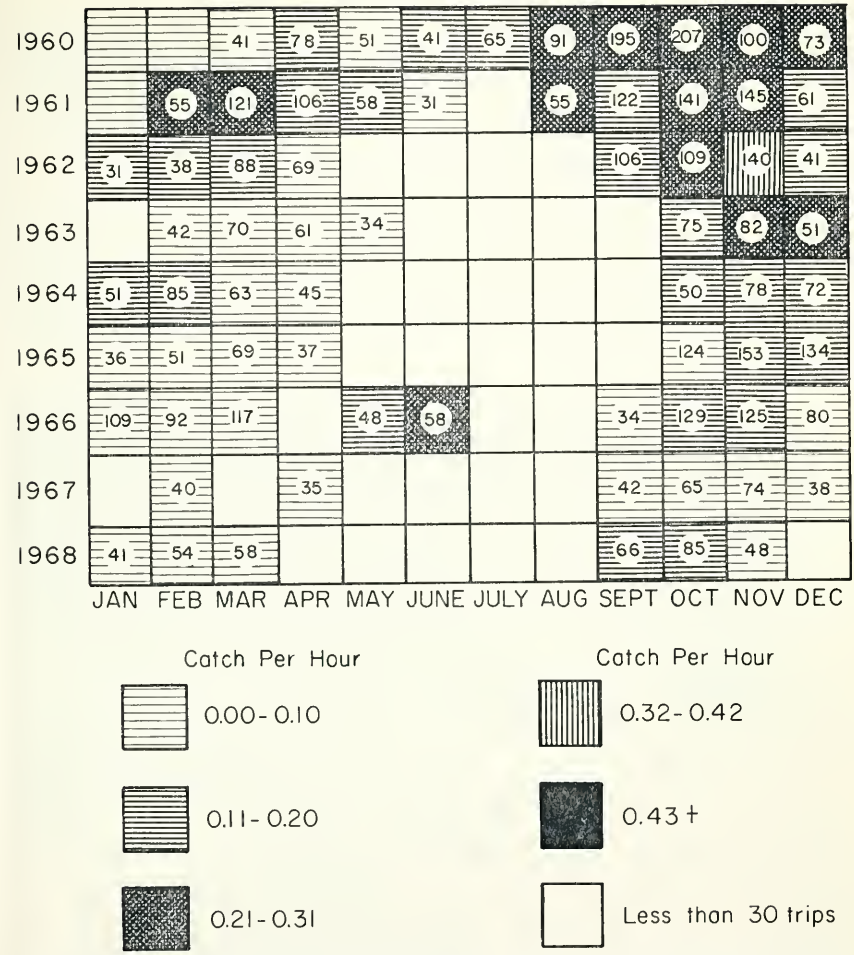

FIGURE 6. Monthly catches per unit of effort for striped bass by anglers fishing from full-day party boats in Block 301 (numbers in squares are the number of trips in that month).

Block 488—Northern San Francisco Bay

Fishing effort as measured by angler days continued the upward trend which started in 1957 (Chadwick, 1962). While effort dropped after 1964, it remained a fairly constant proportion of the total effort (Table 4). Several important factors led to this increase: a summer and fall fishery utilizing deepline trolling techniques developed in the mid 1950's; and a winter fishery dependent on a spawning population of Pacific herring (*Clupea pallasi*) occurs in some years (Chadwick, 1962). In 1962, live bait fishing, including chumming, attracted many people and was very successful. Only one boat was equipped for chumming in 1962 and 1963, and two boats in 1964. These boats dominated party boat fishing in this block from 1963 to 1965, and some incompleteness in reporting significantly affects apparent trends in effort.

The catch per hour started declining in 1963 after increasing steadily since 1954. Prior to 1965, good fishing was experienced in this block nearly year around (Figure 7). Subsequently the winter and spring fishery was almost nonexistent. Average weights increased significantly, although not to the extent reported in other areas.

Block 303—The Delta

Party boat effort in the Delta has dropped steadily and presently is of insignificant proportions. The large number of skiffs and cruisers under private ownership contributed greatly to the decline (Chadwick, 1962). The 9-year mean number of angler days was 335, with 322 fish caught. In 1968 only 25 bass were landed on full-day boats in this block. Mean weight estimates in recent years are of little value due to such small samples.

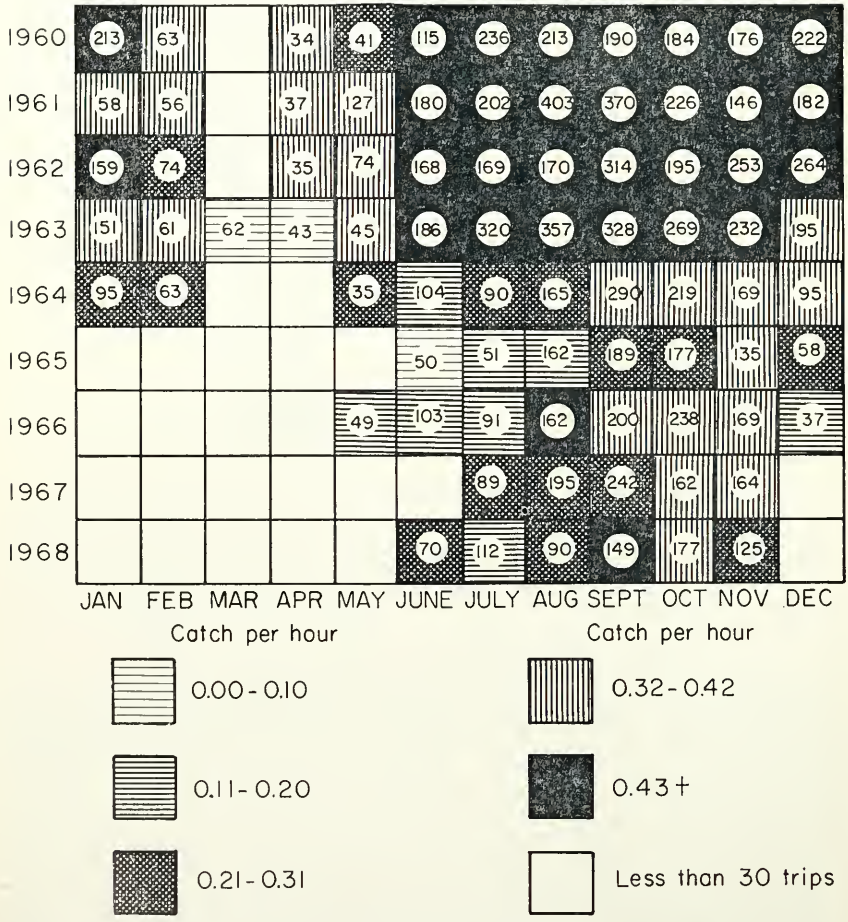

FIGURE 7. Monthly catches per unit of effort for striped bass by anglers fishing from full-day boats in Block 488 (numbers in squares are the number of trips in that month).

Block 302—Suisun Bay

The 9-year mean angler days reported in this block was 195 days with a range of 56 to 579. The mean number of striped bass caught during this period was 90. The effort nearly doubled and the catch decreased from the 1948–59 mean. The mean catch per angler was 0.5 compared with 1.8 for the 1949–59 period. Part of this lower success is likely due to unsuccessful sturgeon effort reported in this block.

Block 489—South San Francisco Bay

A mean 319 angler days were expended to catch an annual average of 436 striped bass. Though effort was never very high, it fluctuated considerably, ranging from a low of 25 angler days in 1964 to a high of 795 angler days in 1967. Both the effort and catch are up from the 1949–59 mean of 252 angler days and 146 bass. The mean catch per angler day for 1960–68 was 1.4 compared with 0.6 for the 1949–59 period.

THE OCEAN FISHERY

Prior reports by Calhoun (1949) and Chadwick (1962) dealt only with the inland blocks described here. Party boat fishing in the ocean previously has been of minor importance. Calhoun (1949) indicated that only occasional party boat forays were made in the Pacific Ocean. In the late 1950's bass were reported from the ocean but an unknown portion of these were actually caught in San Francisco Bay while on the return to home port (Chadwick, pers. comm.). To some extent this may be true for the period of this report. However, it does appear that the ocean party boat fishery has become relatively more important now than during the 40's and early 50's, especially since party boat effort has declined markedly in Blocks 302, 303 and 308. It is also likely that the ocean catch is underestimated significantly because some of the more successful operators did not report all their trips.

TABLE 5—**Summary of Full-Day Party Boat Reports from the Pacific Ocean**

Year	Number of anglers reported	Percentage of total	Number of striped bass reported	Percentage of total	Catch/ angler day	Mean weight	*Weight of bass caught in the ocean as percent total weight reported
1960	3,446	14.8	1,760	4.4	.51	9.2	7.0
1961	355	1.6	557	1.2	1.56	6.2	1.4
1962	3,387	14.9	3,158	7.4	.93	9.9	11.5
1963	5,174	17.5	4,604	8.7	.89	11.5	12.9
1964	2,354	13.2	2,293	9.7	.97	10.6	9.8
1965	2,865	19.0	1,646	12.6	.57	14.6	15.3
1966	3,430	16.2	4,966	17.6	1.44	15.4	27.1
1967	3,290	18.8	2,962	16.2	.90	14.6	19.8
1968	1,221	7.4	1,211	7.5	.99	12.9	9.7
1960–68 mean	2,835	13.7	2,573	9.5	.91	11.6	---

* Includes weight of bass caught with sturgeon.

The data indicate that the number of bass caught in the ocean as a percentage of the total increased from a low of 1.2% in 1961 to a high of 17.6 in 1966 (Table 5). The number of angler days reported in ocean blocks varied from 1.6 to 19.0% of the total but exhibited no definite trend. Many of the bass reported may have been caught incidental to the salmon fishery so that effort actually spent fishing for bass cannot be determined.

The mean weight reported was higher than for any of the inland blocks and show the same trend toward larger bass in recent years. The biggest change occurred in 1965 when the mean weight increased 4 lbs. from the previous year to 14.6 (Table 5). The ocean fishery contributes a higher percentage of total weight than of total numbers due to the larger average size (Table 5).

TABLE 6—Agreement of Mean Weights Reported on Full-Day Party Boats in Block 488 and Estimates Made From Gill Net Length-Frequencies

Year	Block 488 Daily boats x lbs	Gill net x lbs*	Difference (%)
1958	5.1	5.7	−10.5
1959	5.5	5.4	+1.8
1960	6.0	6.0	0
1961	5.9	6.4	−7.8
1965	9.9	8.5	+16.5
1966	9.4	9.6	−2.1

* For a description of gill nets and their operation, see Chadwick (1967). Mean weight estimated by Robinson's (1960) length-weight relationship applied to each inch interval.

The increasing importance of the ocean fishery is compatible with recent migration patterns. Chadwick (1967) found that striped bass tend to migrate farther seaward in recent years compared with the early 1950's. This trend has probably been greater in the 63–68 period since the average size of bass has been increasing and the movement of bass seaward is correlated with bass size (Chadwick, 1967).

POPULATION TRENDS

Party boat catch rates may not reflect population trends accurately, so inferences about population trends should be drawn cautiously.

A major potential cause of error is changes in migration patterns. Striped bass tended to migrate farther downstream and remain there longer during the study period than they did in the early 1950's (Chadwick, 1967). The marked increase in party boat fishing in northern San Francisco Bay can be attributed partially to this migration change, so the changes in catch rates are not true reflections of population differences between the early 1950's and the current period.

On the other hand, annual variations in migrations during the 1960–68 period have been relatively small (Chadwick, 1967; Miller, unpublished data) in comparison to the differences between this period and the early 1950's. Hence, catch rates during the 1960's have been affected less by migration changes, although fluctuations in availability in the Delta (Miller and McKechnie, 1969) suggest that such fluctuations cause indices based on catch rates to be imprecise throughout the fishery.

The changes in angling methods in San Francisco Bay have already been noted as a factor causing biases during the current period.

Calhoun (1949) and Chadwick (1962) used fall catches in Blocks 301 and 308 and yearly catches in Block 303 as measures of trends in population size. Effort in Block 303 has become so insignificant that it no longer provides a useful index. Catch rates have declined through the current period in Blocks 301 and 308 in the fall (Figure 8), but the change in migration patterns and the initiation of a sizable sturgeon fishery undoubtedly have contributed to this decline.

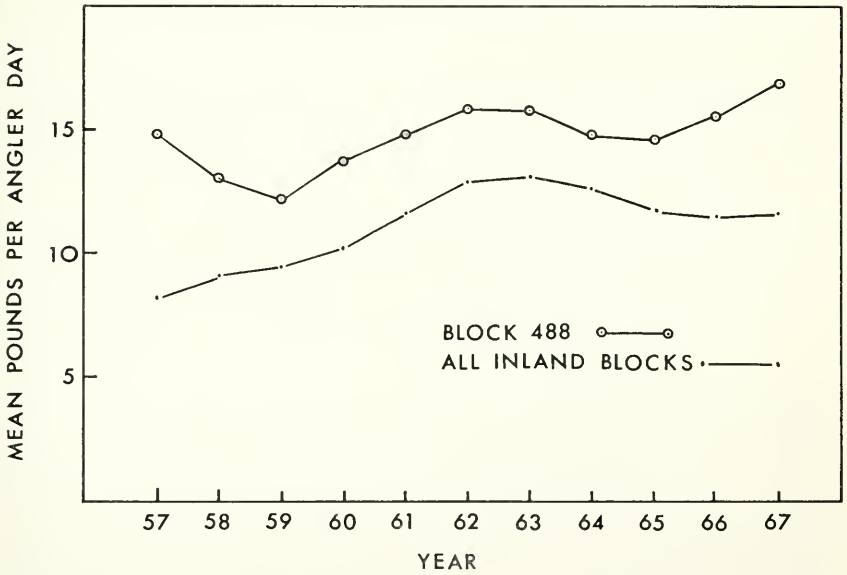

FIGURE 8. Three-year moving average of mean pounds per angler day for full-day party boats (based on 3-year moving average of mean weights reported and 3-year moving average of mean catch per angler day).

The size of bass in the fishery also provides information on population trends, although weights have to be used even more cautiously than numbers because they are estimates rather than counts. The differences in mean weights reported for half-day and full-day boats in Blocks 301 and 308 suggest biases in reporting. However, several sources indicate the general observed trend of increasing weight is real. One source is that mean weights of bass caught in gill nets during tagging operations in the Delta have increased and agree closely with reported mean weights from Block 488 (Table 6).

Another source is the increase in size of fish in the party boat fishery has been paralleled by a similar increase in the Delta fishery from 1959 to 1965 (Miller and McKechnie, 1969). The increase in the Delta was due to an increase in the average age of bass in the catch (Miller and McKechnie, 1969), and growth rates in the population have not changed (Miller and Orsi, 1969). There have been no changes in migration or mortality rates (Chadwick, 1967 and 1968; Miller, unpublished data) which could cause this change in size independent of size

changes in the population. Hence, the change undoubtedly reflects an increase in the average age of bass in the population.

While several of the conditions discussed above make party boat catch rates an imprecise measure of population trends, the nearly steady decline in fishing success in all parts of the fishery after 1963 and the increase in average age are evidence that recruitment and population size have declined since 1963.

Although the catch per angler day for all inland blocks has declined since 1963 (Table 1), the overall trend in terms of weight per angler day has been upward since the late 1950's and has been relatively stable since 1961 (Figure 8). The trend in north San Francisco Bay has generally paralleled the overall trend although the average size of bass was initially greater.

These data suggest that while the numbers of bass in the population have decreased, there has been some compensation in terms of biomass due to the increase in the average weight of bass in the population.

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UPPER LETHAL TEMPERATURE AND THERMAL SHOCK TOLERANCES OF THE OPOSSUM SHRIMP, *NEOMYSIS AWATSCHENSIS*, FROM THE SACRAMENTO-SAN JOAQUIN ESTUARY, CALIFORNIA[1]

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Temperature tolerance tests were performed on adult opossum shrimp *Neomysis awatschensis*, collected in the Sacramento-San Joaquin Estuary from July 1968 to October 1969.

The upper lethal temperature for adult *N. awatschensis* was between 75.6 F and 77.8 F as determined from 48-hr thermal bioassays.

The tolerance of adult *N. awatschensis* to rapid increases in temperature decreased when the acclimation temperature increased. Rapid temperature rises of 25 F or less caused little or no mortality provided the test temperature did not reach 87 F. Survival was inversely related to temperature above 87 F. Rises of more than 25 F caused significant mortalities even though the maximum temperature did not reach 87 F. Survival decreased rapidly with increased exposure time at lethal temperatures.

INTRODUCTION

Neomysis awatschensis Brant is an important food for striped bass, *Morone saxatilis*, and other fishes in the Sacramento-San Joaquin Estuary (Heubach, Toth and McCready, 1963; Ganssle, 1966; Radtke, 1966; Stevens, 1966a, b; Turner, 1966a, b; Thomas, 1967).

The *N. awatschensis* population in the estuary is centered much of the year in the Antioch-Pittsburg area (Turner and Heubach, 1966; Heubach, 1969). Existing and proposed power generating plants are also in this area. In California thermal power plants, the condenser cooling water is raised a maximum of 15-25 F above the ambient water temperature in 4-9 seconds, and maintained at the elevated temperature for 1-6 minutes before discharging into the receiving water (Adams, 1969a). The maximum temperature rise at existing and proposed plants in the Delta is 18 F.

N. awatschensis near the plants might be affected in two ways: (i) exposure to the heated effluent and (ii) entrainment in the condenser cooling water and exposure to a rapid temperature rise of as much as 18 F upon passage through the steam condenser. Therefore, experiments were designed to test the upper lethal temperature and rapid temperature rise tolerances of *N. awatschensis*. Temperature tolerances were defined only for adults, because preliminary tests indicated that adults were not as hardy as juveniles. Hence, adult requirements are controlling in defining suitable power plant operating criteria.

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[2] Presently assigned to Lake Almanor Fisheries Investigation, Region 2, California Department of Fish and Game.

METHODS

The shrimp were collected from the Delta during all seasons. They were netted at salinities ranging from 0.02 to 1.9 ppt chloride. Delta water was taken when the animals were collected and was used in all experiments.

The animals were placed into a 10 mesh/inch stainless steel screen basket in a plastic-lined ice chest two-thirds full of water for transport to the laboratory. Adults became separated from juveniles during transport because juveniles (less than 7 mm length) swam through the screen openings and the adults remained in the basket. Battery powered aerators aerated the water.

The animals were held within 0.5 F of the capture temperature for 48 hr before testing began. The water was filtered and aerated continuously during this period.

The shrimp were siphoned through 3/16 inch ID Tygon tubing into 2-liter battery jars for the temperature tests. A small dip net was used to concentrate the animals in the holding tank to facilitate capture by the siphon. The animals were counted with a hand tally as they passed through a section of tubing laid across a white background. The speed of transfer was controlled by raising and lowering the battery jar. The shrimp were tested in groups of 100 with 3 replicates at each test condition.

The battery jars were filled only to about 5 cm from the top with water. This prevented the shrimp from jumping out. Shrimp that jumped and became stuck to the jar were eliminated from the original count. *N. awatschensis* are negatively phototrophic so the laboratory lights were left on continuously to minimize jumping.

The water in each battery jar was aerated with compressed air delivered through an air stone. Temperatures under test conditions were normally maintained within 0.2 F of the desired temperature.

The water in the test and control jars was changed once during the 48-hr test period of the upper lethal experiments. The water was removed by siphoning through $\frac{1}{2}$ inch tubing screened at the intake to prevent loss of the animals. The jars were filled again with river water at the test temperature. Dead animals were removed once or twice a day to prevent fouling of the water.

Control groups were handled identical to the test groups. Test survivals presented in this paper, except for true survivals in Tables 1 and 2 and as noted in the upper lethal temperature analysis, were adjusted by dividing the actual test survival by the control survival.

N. awatschensis were fed dried Daphnia during the holding and test periods. Cannibalism was prevented by making food available at all times.

DESCRIPTION OF TESTS

Upper Lethal Temperature

Fry, Brett and Clawson (1942) and Brett (1944) developed the techniques used to derive the upper lethal temperature of *N. awatschensis*.

Battery jars of animals, at each acclimation temperature, were placed into 3 or 4 constant temperature baths at different test temperatures. The test temperatures varied between experiments. They ranged from 2 to 27 F above acclimation. The highest increases were in those

tests with the lowest acclimation temperature, and the lowest increases were in those tests with the highest acclimation temperature. The period of temperature adjustment in the jars was approximately 1 hr for a 20 F rise with proportionally shorter times for lesser temperature rises and proportionally longer times for higher rises. Survival was measured after 48 hr.

For each acclimation group, the mean percentages surviving at each test condition were plotted against their respective test temperatures. A line was fitted to the points, by eye, and the LD_{50} estimated by interpolation.

Experimental LD_{50} values were plotted against their corresponding acclimation temperatures and a line fitted to the points using the method of least squares. The upper lethal temperature is the point on the line where the acclimation temperature equals the lethal temperature (Figure 1).

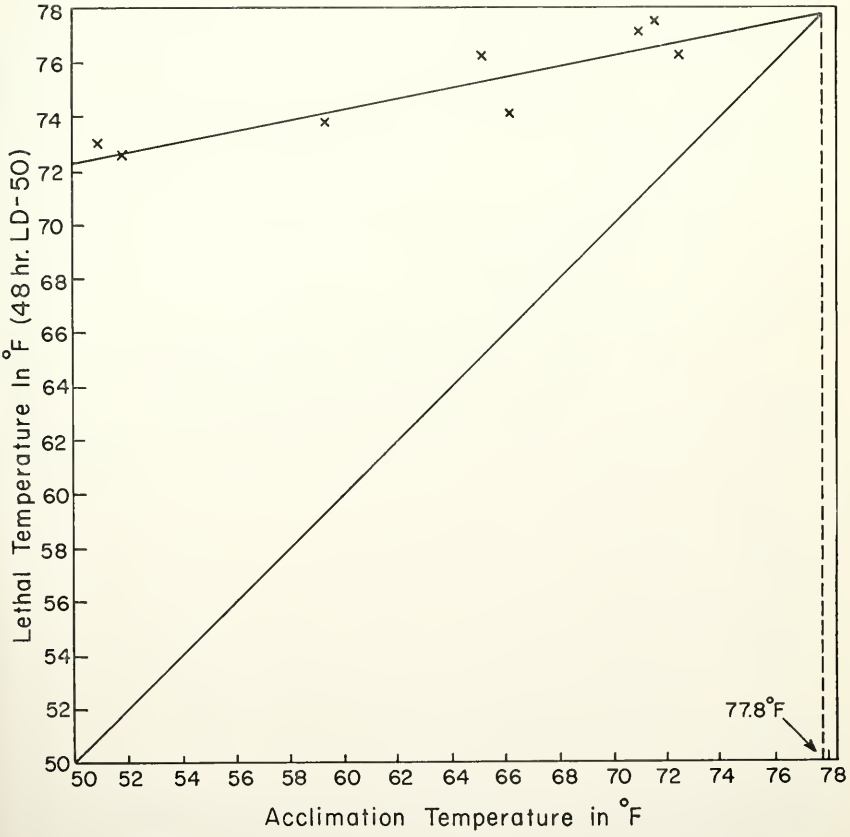

FIGURE 1. Estimation of upper lethal temperature for *N. awatschensis*.

Rapid Temperature Rise

For each test, 100 *N. awatschensis* and 775 ml of water at acclimation temperature were poured into a battery jar. An equal volume of warmer water was added over a 10-sec period. At the same time the

mixture was rapidly stirred with a thermometer. The temperature of the water to be added was derived by multiplying the desired rise by 2 and adding the product to the acclimation temperature. For example, if a 10 F rise was desired, the added water was 20 F warmer than the acclimation temperature. The elevated temperatures were generally maintained for either 0, 2, 4 or 6 min. Animals in the zero minute exposure group were placed into a water bath at acclimation temperature to begin cooling immediately after the warm water was added. The other groups were held the required time in a water bath at the test temperature and then placed into the acclimation temperature bath. Temperatures were measured immediately after mixing and at 2-min intervals for the next 10 min. Thereafter temperatures were measured less frequently. Survival was measured at the end of 24 hr.

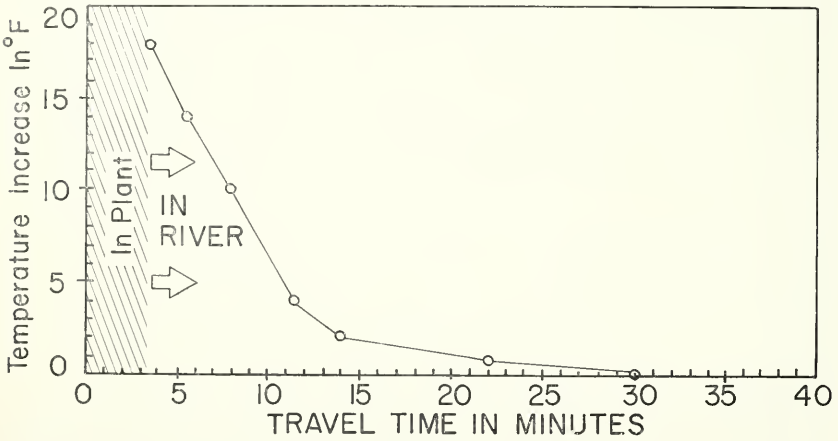

FIGURE 2. The decay of temperature with time for a mass of water moving through the cooling water system of the Pittsburg Power Plant, California (Adams, 1969b).

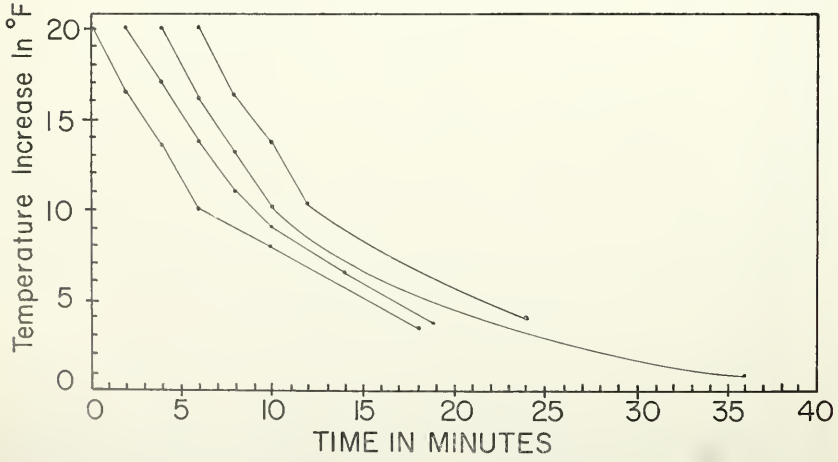

FIGURE 3. Temperature decay for four laboratory experiments. Temperatures were maintained 0, 2, 4, and 6 min before cooling.

The temperature decay during the cooling period simulated very closely the actual thermal conditions at the Pittsburg power plant (Figures 2 and 3).

Some *N. awatschensis* were held after the normal testing period to test the delayed effects of rapid temperature rise on survival and reproduction. The animals observed for delayed effects were kept in 5-gallon aquaria at their acclimation temperature. The reproduction tests were on females carrying eyed embryos in the brood pouch.

RESULTS

Preliminary Tests—Adult Survival vs. Juvenile Survival

Three rapid rise tests and two upper lethal tests were performed on both adult and juvenile *N. awatschensis* during development of the experimental design. The true survival of adults was as low or lower than that of the juveniles in all tests (Tables 1 and 2). In two of the rapid rise experiments poor survival in the adult controls resulted in higher adjusted survival percentages for adults than for juveniles at elevated temperatures. In the other rapid rise test and in both upper lethal tests, the adjusted survival percentages were lower for adults than for juveniles.

These tests indicate that adults are probably not as resistant as juveniles to temperature changes. All subsequent testing was on adults.

TABLE 1—**Preliminary Rapid Temperature Rise Experiments Performed on Adult and Juvenile *N. awatschensis*** [1]

Acclimation temperature (F)	Temperature rise (F)	Survival percentages[2]			
		Juveniles		Adults	
		True survival	Survival adjusted for deaths in controls	True survival	Survival adjusted for deaths in controls
68.5	0 (control)	94.0	100.0	82.7	100.0
	5	93.7	99.7	89.2	107.9
	10	94.3	100.3	87.2	105.4
	20	90.0	95.7	84.2	98.2
69.5	0 (control)	94.7	100.0	90.3	100.0
	5	96.6	102.0	89.6	99.2
	10	95.7	101.1	81.9	90.7
	20	81.3	85.9	72.3	80.1
70.0	0 (control)	82.0	100.0	76.2	100.0
	5	81.0	98.8	77.2	101.3
	10	83.0	101.2	83.0	108.9
	20	78.1	95.2	69.2	90.8

[1] These tests were conducted while transportation, holding, feeding and temperature control methods were being developed. Results inconsistent with findings presented later in this paper are due to irregularities in the experimental technique. The period for which the shrimp were subjected to the maximum temperature varied between tests. The time interval ranged from a few seconds to one minute. Adult and juvenile shrimp were given equal treatment in all tests. Survival was measured after 24 hours.

[2] Mean of three groups of 100 animals each.

TABLE 2—**Preliminary Upper Lethal Temperature Tolerance Experiments Performed on Adult and Juvenile *N. awatschensis*** [1]

Acclimation temperature (F)	Test temperature (F)	Survival percentages[2]			
		Juveniles		Adults	
		True survival	Survival adjusted for deaths in controls	True survival	Survival adjusted for deaths in controls
69.0	69.0 (control)	94.7	100.0	81.7	100.0
	74.0	86.6	91.4	68.0	83.2
	79.0	58.3	61.5	19.3	23.6
	84.0	0.0	0.0	0.0	0.0
	89.0	0.0	0.0	0.0	0.0
66.5	66.5 (control)	93.6	100.0	90.3	100.0
	71.5	95.0	101.5	87.9	97.3
	76.5	85.3	91.1	72.5	80.3
	81.5	0.0	0.0	0.0	0.0
	86.5	0.0	0.0	0.0	0.0

[1]These tests were conducted while transportation, holding, feeding, and temperature control methods were being developed. Results inconsistent with findings presented later in this paper are due to irregularities in the experimental technique. Survival was measured after 24 hours.
[2]Mean of three groups of 100 animals each.

Upper Lethal Temperature

When test survival percentages were adjusted for mortality in the controls, the lowest LD_{50} temperature was 72.6 F at an acclimation temperature of 51.8 F. The highest LD_{50} temperature was 77.4 F at an acclimation temperature of 71.6 F. The upper lethal temperature of *N. awatschensis* was estimated to be 77.8 F (Figure 1).

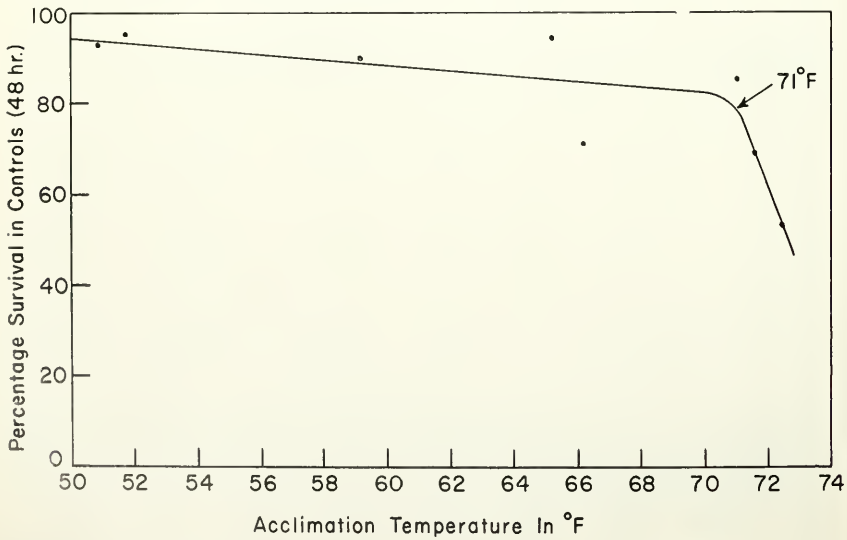

FIGURE 4. Effect of acclimation temperature on control survival in the upper lethal temperature experiment.

Survival in the controls ranged from 52 to 95%. Mean control survival was 81%. Control survival was affected by temperature. It decreased as the acclimation temperature increased. The rate of this decrease intensified at 71 F (Figure 4). This relationship suggests that the upper lethal temperature is biased upward as some of the adverse effects of heat would have been cancelled when the actual test survival percentages were divided by the control survival percentages.

The upper lethal temperature was also estimated with no adjustment for mortality in the controls. This temperature is 75.6 F and probably biased downward because of mortality not induced by heat. Some mortality was almost certainly caused by extraneous factors such as handling or disease. Therefore, the unbiased upper lethal temperature is between 75.6 F and 77.8 F.

Rapid Temperature Rise

Survival was tested at acclimation temperatures ranging from 46.4 F to 72.1 F. Adjusted survivals ranged from 0 to 102% (Table 3). Control survivals ranged from 80% at the highest acclimation temperature of 72.1 F to 98% at the lowest acclimation temperature of 46.4 F. The mean control survival was 93%.

Control survival decreased as the acclimation temperature increased, but the results of these tests were not biased. The experiment was to

TABLE 3—**Effects of a Rapid Temperature Increase on Survival of *N. awatschensis***

Acclimation temperature in F	Percent survival in controls	Temperature rise in F	Percent survival[1]					
			Exposure period					
			0 min	0.5 min	2 min	4 min	5 min	6 min
46.4	98.5	9	99.5	--	--	--	--	--
		18	--	--	--	99.5	--	--
		25	--	--	--	98.8	--	--
		32	100.0[2]	--	--	88.3	--	--
50.0	98.3	27	98.0	--	94.9	91.2	--	87.5
		36	53.9[3]	11.2	2.3	1.0	--	--
57.0	96.0	10	100.7	--	--	98.6	--	--
		15	100.0	--	--	98.2	--	--
		19	100.0	--	--	--	98.2	--
		25	100.6	--	--	96.1	--	--
62.1	97.7	15	98.9	--	95.4	98.3	--	95.1
		20	92.1	--	90.7	90.8	--	92.5
68.0	94.5	15	98.3	--	99.0	95.9	--	95.9
		20	59.0	--	26.5	27.5	--	15.5
70.1	83.4	10	102.2	--	101.0[2]	103.4	--	95.8
		15	99.7	--	100.7	98.3	--	102.2
		20	59.2	--	13.2	0.0	--	0.0
72.1	80.0	15	100.7	--	99.4	85.3	--	81.1
		18	69.4	--	24.6	0.4	--	0.0
		20	12.9	--	0.0[2]	--	--	--

[1] All percentages represent survival for three test groups of 100 animals each, except where noted. Survivals are expressed as a percentage of control survival.
[2] Two test groups of 100 animals each.
[3] One test group of 100 animals.

determine effects of temperature increase so it was desirable to eliminate effects of the base temperature. This was done by expressing survival as a percentage of control survival.

N. awatschensis at acclimation temperatures of 57.0 F to 72.1 F were exposed to rises of 10 to 25 F. Little or no mortality occurred until the maximum temperature reached 87 F. The survival of *N. awatschensis* at temperatures above this critical level decreased as the exposure time increased, and at each exposure interval there was a strong inverse relationship between survival and temperature (Figure 5).

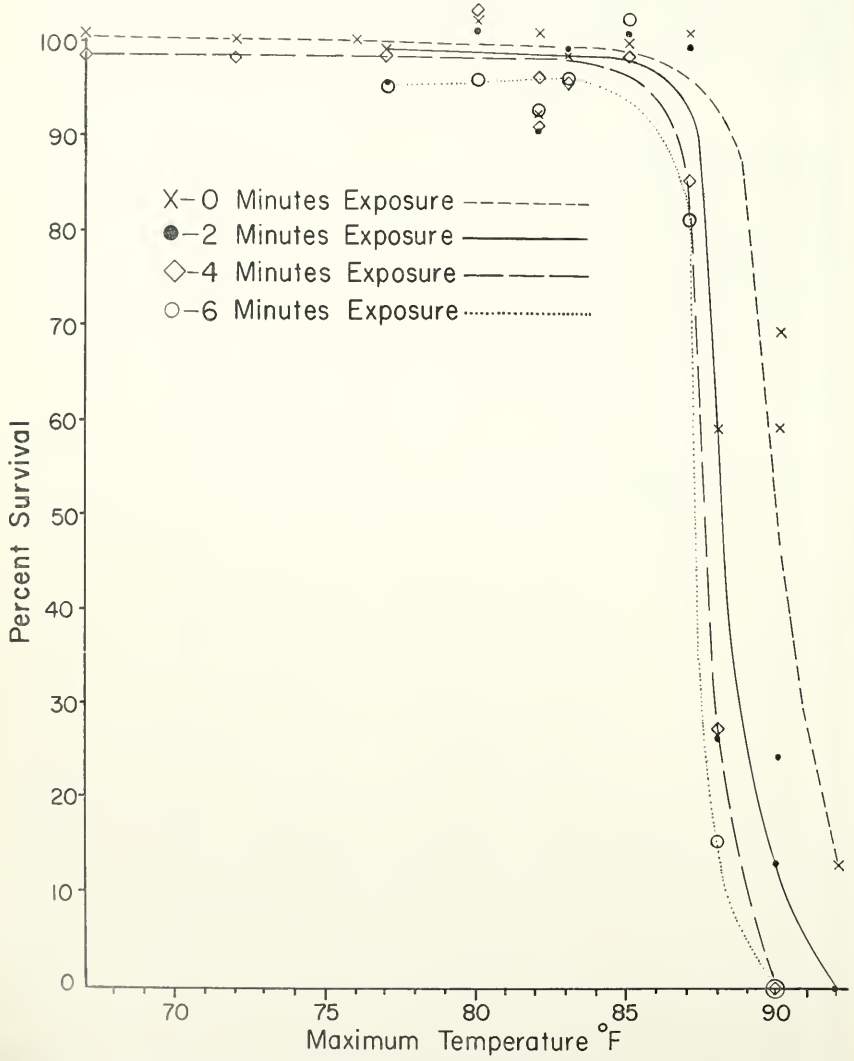

FIGURE 5. Effect of maximum temperature attained during rapid temperature rise experiments on survival of *N. awatschensis* acclimated at temperatures between 57.0 and 72.1 F.

N. awatschensis acclimated at 46.4 and 50.0 F were exposed to temperature rises as high as 36 F. Significant mortalities occurred with temperature rises of 27 F to 36 F even though the critical temperature of 87 F was not reached (Table 3).

Survival declined as the temperature rise increased in nearly every experiment (Table 1). This decline was most pronounced at the highest acclimation temperatures (Figure 6).

There was no delayed mortality attributable to the rapid temperature rise when 173 shrimp exposed for 6 min to a 27 F rise from a base temperature of 50.0 F were kept for 7 days. Eighty-eight percent of the test animals survived the holding period while only 83% of the controls survived.

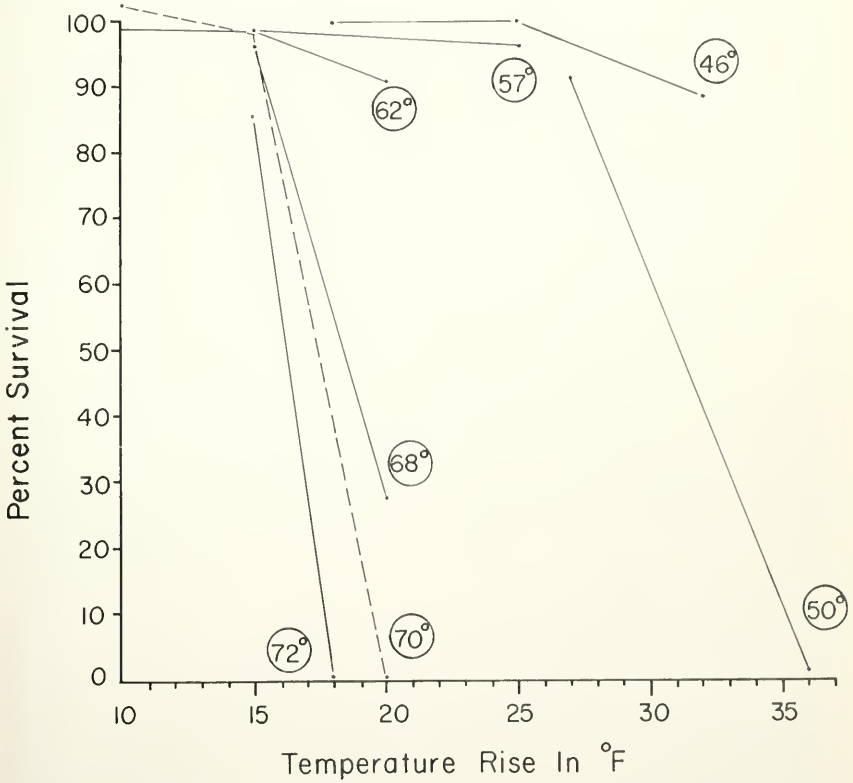

FIGURE 6. Effect of temperature rise on survival of *N. awatschensis* from seven acclimation temperatures. Acclimation temperatures are circled. All data are for a 4 min exposure at the test temperature.

Tests for delayed effects of rapid temperature rise on reproduction were inconclusive. In one experiment at a base temperature of 62.1 F I held for 5 days, 9 gravid females subjected to a 15 F rise, 9 gravid females subjected to a 20 F rise, and 9 control females. Eight females subjected to the 20 F rise survived while only 6 control females and 3 females subjected to the 15 F rise survived. The control females pro-

duced 101 young, which was greater than the 53 young produced by the females subjected to the 20 F rise, but less than the 116 young produced by the females subjected to the 15 F rise. In another experiment at an acclimation temperature of 70.1 F I held 20 control females and 20 females exposed to a 15 F rise for 4 days. There was no hatching in either group.

SUMMARY AND DISCUSSION

Tests made during the development of the experimental design indicated that adult *N. awatschensis* are not as hardy as juvenile *N. awatschensis.*

No studies on the effects of thermal shock on *Neomysis* have been previously reported. Wilson (1951) reported an upper lethal temperature of 74.5 F for *N. mercedis* Holmes (now *N. awatschensis*) from British Columbia. This was based on 48-hr experiments at 3 acclimation temperatures.

The difference between Wilson's value of 74.5 F and the upper lethal temperature reported here may reflect what Kinne (1963) termed "genetic adaptation". *N. awatschensis* in the Sacramento-San Joaquin Estuary are at the southern limit of their range (Banner, 1954) and have possibly adapted to warmer conditions than the shrimp studied by Wilson in British Columbia.

A closely related mysid, *Neomysis americana*, has a greater tolerance to higher temperatures. Mihursky (1969) reports 24-hr LD_{50} temperatures between 31 C (87.8 F) and 33 C (91.4 F) for *N. americana* in the Patuxent River estuary. In the summer, surface water temperatures approach these levels in that estuary.

The upper lethal temperature is obviously not a satisfactory environmental condition, and these experiments do not define with certainty how much lower temperatures in the environment must be to be satisfactory. *N. awatschensis* populations in the Sacramento-San Joaquin Estuary generally decrease when water temperatures exceed 72 F (Heubach, 1969). The calculated upper lethal temperature and the sharp decrease in survival of controls at acclimation temperatures over 71 F support the hypothesis that the decreased survival Heubach observed in the estuary is caused by temperature, with temperatures in the low 70's unsatisfactory.

The most significant findings from my rapid temperature rise experiments were: (i) the tolerance of *N. awatschensis* to a rapid temperature rise decreases with increasing acclimation temperatures, (ii) there is an inverse relationship between survival and exposure time at high temperatures, and (iii) adult *N. awatschensis* can withstand a rapid temperature rise up to 25 F above acclimation temperature provided the exposure time is short and the ultimate temperature does not reach the critical temperature of 87 F.

The lethal effects of a rapid temperature rise on *N. awatschensis* were immediate. Shrimp surviving the first few hours survived the entire 24-hr test period. There was no delayed mortality observed within 7 days.

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THE KOKANEE SALMON IN LAKE TAHOE[1]

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Large numbers of kokanee salmon (*Oncorhynchus nerka*) fry were stocked in Lake Tahoe from 1949 through 1955. Kokanee became established but the population remained at a low level until 1963 when a dramatic increase in the number of spawners was observed. A fishery finally developed in 1967. Major spawning concentrations occur in Taylor Creek and along the shores of McKinney Bay. In most years from 1960 through 1968 virtually the entire Taylor Creek run was composed of a single age group from certain strong year classes. Presence of strong year classes suggests high survival of naturally-spawned fish. There is some evidence, however, of high egg retention. Lake Tahoe kokanee grow rapidly and a trend toward increasing growth rates since 1961 is suggested. Their length-weight relationship was log W = —3.26090 + 2.91063 log L. Their diet consisted mostly of cladocerans. They are widely distributed in the limnetic zone and strongly surface oriented, except during the summer and early fall when large schools form off Taylor Creek at depths from 50 to 120 ft. Under these conditions fishing is feasible and an intensive deepline-troll fishery has developed. Efforts should be made to enlarge this fishery in space and time provided the average size of the kokanee does not decline below an acceptable level.

INTRODUCTION

The status of the kokanee salmon in Lake Tahoe has changed considerably in recent years. During the summers of 1967 and 1968, kokanee fisheries developed in Tahoe for the first time since the initial kokanee introductions in the 1940's and 1950's. Since the early 1960's, moreover, kokanee spawning runs in Taylor Creek, the major spawning tributary, have increased substantially. Beach spawning during this period has also increased.

Fraser and Pollitt (1951), Richard (1954) and Corlett and Wood (1958) document the status of the kokanee in the first years following their introduction. They observed small runs in many tributaries but only in Taylor Creek did these runs persist after the early plantings ceased. No kokanee were observed in the sport fishery.

In 1960 the cooperative California and Nevada Lake Tahoe Fisheries Study was begun. From 1960 through 1966 we collected data on various aspects of the life history of the kokanee in the lake. This report describes the development of the present fishery, and summarizes the information collected during the study on the spawning, age and growth, food habits and distribution of kokanee in Lake Tahoe.

[1] Accepted for publication July 1970. This work was performed as part of Dingell-Johnson Projects California F-21-R and Nevada F-15-R, "Lake Tahoe Fisheries Study", supported by Federal Aid to Fish Restoration funds.

[2] Presently on leave of absence with the United Nations Food and Agriculture Organization, Jinja, Uganda.

STOCKING HISTORY

Kokanee first were introduced in 1944 when fry held at the Tahoe State Hatchery were released accidentally. From 1949 through 1955, fry were planted annually by the California Department of Fish and Game and/or the Nevada Fish and Game Commission at numerous points along the lake shore and in most of the major tributaries (Richard, 1954; Corlett and Wood, 1958). Approximately 4.5 million kokanee were planted during this period. The eggs for these plants were ob-

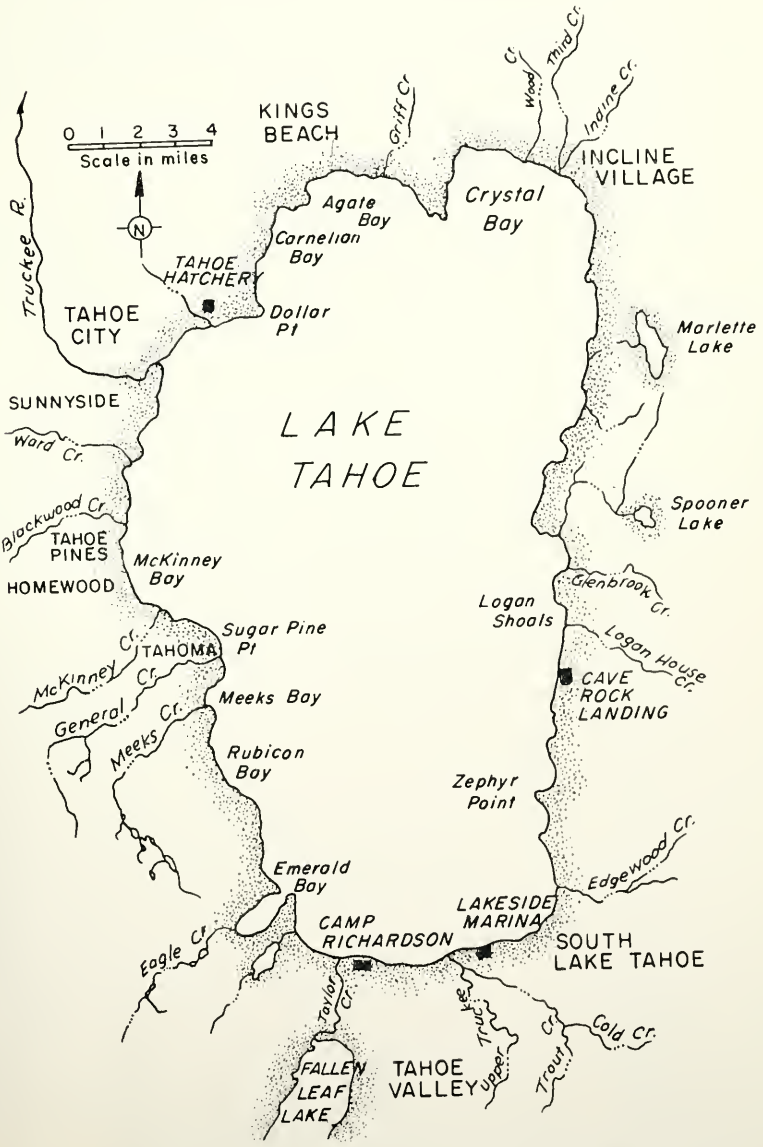


FIGURE 1. Map of Lake Tahoe showing Taylor Creek and areas referred to in text.

tained from various sources in Idaho, Montana, and Washington. No kokanee were planted by either state from 1956 through 1963.

In 1964, 1965, and 1966 the Nevada Fish and Game Commission planted 6.1 million fry on the Nevada side of the lake. Eggs for the 1964 and 1966 plants were obtained from Washington; the egg source for 1965 was Taylor Creek. From 1967 through 1969 California planted over 6 million fry from eggs obtained from the developing runs at Taylor Creek. Nearly all of the fish planted during the first 2 years were released in Taylor Creek or in Tahoe near Taylor Creek. A few, raised at the Tahoe Hatchery, were planted at the Wildlife Conservation Board Boat Ramp near the hatchery, and in the hatchery creek. In 1969 the kokanee were planted off Kings Beach near Griff Creek, and at the Cave Rock Boat Ramp (Figure 1). They ranged in size from 350 to 47/oz.

NATURAL REPRODUCTION

Taylor Creek

The extensive tributary stocking program conducted from 1949 through 1955 produced spawning runs in most of the major Tahoe tributaries in the early 1950's. Nearly all of these runs diminished after the cessation of the program, and currently only Taylor Creek has a naturally sustained run. A few fish are seen occasionally in several of the other tributaries but their contribution to the population is insignificant.

The tributaries to Lake Tahoe are not well suited for kokanee spawning due to their small size, low flows, and poor condition. Taylor Creek, however, seems to be the exception. It has been the major kokanee spawning area at Lake Tahoe since 1960. This is probably the result of good quality spawning gravels and suitable flow patterns made possible by a regulatory dam on Fallen Leaf Lake (Figure 1), and perhaps some modification of typical stream temperatures by Fallen Leaf Lake water. It is only about 2 miles long, however.

Spawning runs in Taylor Creek generally start between the middle of October and the first week in November. They may begin much earlier as did the 1965 run which began in late September. The fish usually complete spawning within 2 to 3 weeks. Stream temperatures during October and November decline rapidly from the mid-50's F to the mid-30's F, remaining at the lower level until April and May when they rise to the mid-50's again. During these months, kokanee fry migrate downstream into Tahoe. Flows usually are allowed to reach low levels in summer and then are increased early in October to accommodate spawning kokanee, brown trout (*Salmo trutta*), and mountain whitefish (*Prosopium williamsoni*). They remain at this level until spring when uncontrolled snowmelt runoff may create very high flows.

With the exception of the 1952 run of 474 fish (Richard, 1954), the spawning runs in Taylor Creek before 1960 were relatively small. In 1960 an estimated 1,800 to 2,000 kokanee ascended Taylor Creek to spawn. The Taylor Creek spawning runs have been surveyed each year since then to determine their size and composition (Table 1). In 1964 the spawning runs increased dramatically over that of previous years and continued at a similarly higher level through 1968. The average size of the run from 1965 through 1968 was about 18,000.

TABLE 1—Kokanee Salmon Spawning Runs in Taylor Creek *

		1960	1961	1963	1964	1965	1966	1967	1968
Estimated size of spawning run		1,800–2,000	250–300	2,500–3,000	25,000–35,000	6,000–10,000	18,000–25,000	5,000–8,000	20,000–25,000
Number measured	Males	393	30	507	222	115	165	92	177
	Females	346	30	340	844	122	431	331	443
Sex ratio†	Males	1.00	1.00	1.00	1.00‡	1.00			
	Females	0.88	1.00	0.67	1.20‡	1.06			
Mean length	Males	17.5	18.6	14.3	17.2	19.4	16.9	20.1	18.6
	Females	15.8	16.7	13.1	16.0	17.9	15.7	19.1	17.5
Length range	Males	13.8–19.2	15.0–21.1	11.9–19.5	15.1–18.5	17.2–21.1	15.3–22.5	18.2–21.8	15.4–20.7
	Females	10.6–17.5	15.2–18.2	11.3–18.5	13.5–17.4	11.9–19.6	14.3–21.3	14.1–20.8	13.9–19.9
Standard deviation of lengths	Males	0.7008	1.3833	0.7807	0.5809	0.6800	1.4404	0.7958	1.0741
	Females	0.7997	0.7838	0.6997	0.5403	0.8792	1.1554	0.8529	0.9269

* The 1962 run was too small to permit significant measurements. It was probably less than 50 fish.
† Unless otherwise noted, sex ratios are based on random samples of spent fish which had spawned naturally in the stream.
‡ Based on 355 males and 425 females collected at random during egg-taking operations.

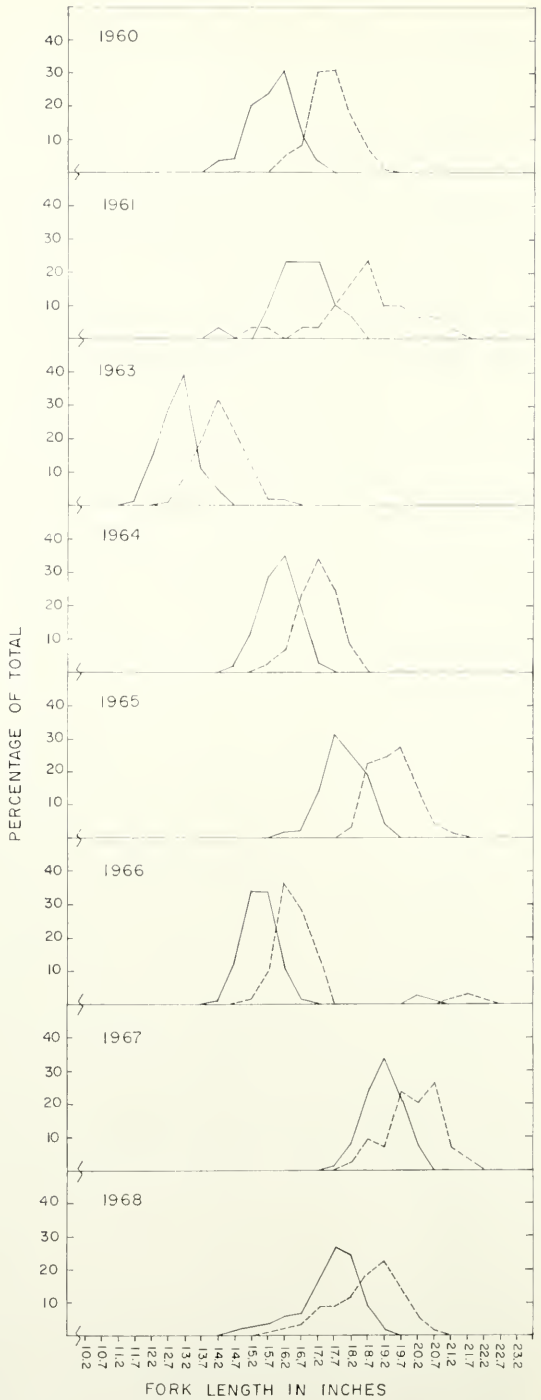


FIGURE 2. Percentage size composition of spent female (——) and male (- - - -) kokanee salmon in Taylor Creek. Values less than 1.0% are not shown.

The size of kokanee spawning in Taylor Creek has varied noticeably through the years since 1960. Mean lengths of males and females ranged from a low of 14.3 and 13.1 inches FL, respectively, in 1963 to a high in 1967 of 20.1 and 19.1 (Table 1). From analyses of the length frequencies and age and growth information, much of this variation appears due to changes in age composition of the spawning run. The progression in the length frequencies taken from 1963 through 1966, for example, suggests that a single year class dominated the run during the first 3 years, and contributed a small portion in the fourth year (Figure 2). Age and growth data from scales taken during this period indicate that 2-year-olds (2+) spawned in 1963, 3-year-olds (3+) in 1964, 4-year-olds (4+) in 1965, and a few 5-year-olds (5+) in 1966. These fish belonged to the 1961 year class and were the progeny of the 1960 Taylor Creek run. Similarly, the majority of the fish spawning in 1966 and 1967 were 2- and 3-year-olds, respectively, belonging to the 1964 year class.

There is some indication that the size of the kokanee population in the lake influences growth rate. For example, the average length of the 2-year-olds returning to spawn in 1963, which were part of the very large 1961 year class, averaged approximately 2.5 inches smaller than fish of the same age returning in 1966. Also, the 3-year-olds returning in 1964 were smaller than those returning in 1967 or 1968.

Kokanee egg taking operations have been conducted at Taylor Creek in recent years. In 1964 California and Nevada collected eggs. Only those fry raised from eggs taken by Nevada were returned to the lake. In 1966, 1967, and 1968 approximately 3.8, 2.0, and 2.3 million eggs, respectively, were taken at Taylor Creek by the California Department of Fish and Game. All of the resulting fry have been returned to Tahoe. Kokanee spawners have been transferred from Taylor Creek to other Tahoe tributaries: 479 in 1964 and 1,110 in 1966.

Lacustrine Spawning

Beach spawning in Tahoe first was observed in November 1954. At that time, two small schools of approximately 100 to 200 fish each spawned along the west shore between Homewood and Tahoe City. Since then numerous observations have been made of kokanee spawning elsewhere along the shore. Most of the major established beach spawning areas are now known. The largest of these occurs along the west shore in the area of McKinney Bay. Some spawning also occurs at Rocky Point between Dollar Cove and Carnelian Bay.

Available data on beach spawning suggest that it contributes sizeably to the kokanee population in Tahoe. Surveys of the McKinney Bay area by boat in 1964 and 1968 produced estimates of approximately 1,600 kokanee spawners from south of Tahoma to Tahoe Pines in 1964, and over 2,000 in 1968, also including the Sunnyside area. Because of the difficulties inherent in observing fish from a moving boat, these estimates are considered low.

Spawning Success

Internal examination of dead spawners commonly disclosed retained eggs. Of 103 dead kokanee examined in Taylor Creek in October 1965, 30% apparently had not spawned at all, 22% had retained about three-

quarters of their eggs, 22% had retained about one-half of their eggs, 15% had retained about one-quarter of their eggs, and only 11% were completely spawned out or nearly so. During the 1967 Taylor Creek run we dissected 43 dead kokanee and found that only 28% had spawned, while 26% were partially spent, and 46% had retained all their eggs (Frantz, 1968). The latter group included both green and ripe fish. We observed the same condition in lake spawners also. Ten dead kokanee examined at Lakeside Marina in 1967 had retained their eggs (Frantz, 1968).

In spite of the observed high egg retention, high survival at some or all stages of the kokanee life cycle in Lake Tahoe is suggested by the development of strong year classes. For example, the 1961 year class that developed from the 1960 Taylor Creek run of 2,000 fish produced the runs in 1963, 1964, and 1965 of between 33,000 and 48,000 fish. An estimated survival of 2% is indicated, assuming that all 2 million (1,000 females averaging 2,000 eggs each) of the potential eggs were deposited. Using the egg retention figures observed in 1965, it may have been that only 77,500 eggs were deposited. This would mean the survival of the 1961 year class was about 52% (assuming that this year class contributed about 40,000 spawners to the 1963–65 runs). This figure may not be unreasonable since kokanee spend little time in the creek after emergence, potential predators in the limnetic zone are few, growth is good, and no fishery existed in those years. These factors will be discussed below.

Although no gravel samples have been taken, the spawning gravels of Taylor Creek, compared with other tributaries, appear relatively free of sand and silt. The short length of stream, below a natural sediment settling basin (Fallen Leaf Lake), and a relatively undisturbed watershed contribute to this condition. Lakeshore spawning substrates, on the other hand, contain a relatively high proportion of fine material, and this may account for some low egg survivals found there. Eyed kokanee eggs were planted at nine locations around the Tahoe shoreline in the winter of 1962. At each site we buried two containers with 100 eggs each, plus local substrate material. Three of the sites were in areas where kokanee now spawn regularly in Carnelian and McKinney bays. The containers were buried on January 16, 1962, and retrieved on March 13, 1962. Survival to the alevin stage occurred only at two of the three areas utilized by spawning kokanee. Percentage survival was about 25 at each of these locations and 0 at the remainder. In January and February of 1969, SCUBA divers sampled six redds located between Tahoma and Sunnyside. Of 97 eggs collected, 43% were alive and most were eyed. Percentage survival in individual redds ranged from 25 to 71.

DISTRIBUTION

Kokanee are widely distributed in Lake Tahoe. We found them scattered throughout the limnetic zone and occasionally collected them near the bottom. Based on collections and fathometer traces, they apparently form schools only in the summer and fall off the southwestern end of the lake. These are mature fish which will later ripen and enter Taylor Creek to spawn.

Two years of intensive sampling with variable-mesh multifilament gill nets set on the bottom captured only 25 kokanee. All but two were taken in September and October. Twenty-five bottom sets with monofilament nets in May and June of 1963 caught 57 kokanee. Fifty-four were taken in a single set at a depth of 50 ft. These fish averaged 9.3 inches and ranged from 8.7 to 10.8 inches.

Kokanee were found in greatest abundance in the limnetic zone. Their distribution in the limnetic zone was determined in 1964 with monofilament gill nets. They were the most abundant species in this zone, comprising 143 (37%) of the total 387 fish caught. They ranged in length from 4.6 to 20.9 inches and averaged 14.1 inches. The remainder were wild rainbow trout (26%), tui chub (*Gila bicolor*) (18%), planted rainbow trout (16%), lake trout (*Salvelinus namaycush*) (2%), and miscellaneous species (1%). Kokanee and wild rainbow were taken in 48% of all sets, planted rainbow in 38%, and tui chubs in 23%. Tui chubs, lake trout, and the miscellaneous species (brown trout, mountain whitefish, and Lahontan redside (*Richardsonius egregius*) were more abundant in nets set relatively close to shore, whereas kokanee and rainbow were more equally distributed between near shore and off shore catches.

Monofilament gill netting and fathometer readings indicated that mature kokanee are strongly surface oriented during all months of the year except July, August, and September. From November through June, 82% of all mature kokanee taken in the surface nets (22 ft deep) were caught in the top 10 ft of the net. Only one kokanee (from 103 ft) was taken in the deeper sets. During July through September, kokanee descend to deeper water. Of 31 kokanee caught in nets set at the surface and in the 50- to 72-ft zone on July 29 and August 25, 1964, only 3 were taken in the surface net and the remainder (90.3%) were scattered from 50 to 72 ft in the deeper net. What appeared to be fish schools were noted on fathometer tapes during August and September of 1964 at depths from about 50 to 120 ft. A mid-water trawl confirmed that these were actually kokanee. In September 1963, our fathometer detected schools of kokanee concentrated at depths from 70 to 100 ft. In October, the kokanee begin moving toward the surface in preparation for spawning. In October 1963 they were concentrated between 15 and 50 ft, with lesser numbers between 0 and 15 and 50 and 90 ft.

The downward movement of kokanee in the summer months appears related to temperature. As temperature increases into the high 50's and low 60's during this period, they descend to the metalimnion where temperatures are 50 to 55 F. Their rise to the surface in October coincides with decreasing water temperature at the surface.

Although kokanee were relatively more abundant than other species in the limnetic zone in 1964, their actual density was quite low. The average catch per day (24 net-hours) in the surface sets from January through May was 0.4 fish, increasing to between 0.9 and 3.2 from June through November and then dropping to about 0.1 in December.

The limnetic zone of Lake Tahoe would seem to afford an excellent habitat for kokanee. The only species which could compete with them for food are the rainbow trout and tui chub, and these occur at lower densities. Piscivorous fishes such as the lake and brown trout rarely

enter this region. Intraspecific competition would probably be the main factor limiting kokanee production.

Young-of-the-Year

The kokanee fry of the 1960 brood-year were sampled in Taylor Creek with two riffle fyke nets (Hallock, Warner, and Fry, 1952) set overnight in April and May 1961. We modified the nets by adding a box at the cod end to capture fish alive. One was set about 100 yards upstream from the mouth and a second about 100 yards downstream from the State Highway 89 bridge crossing (about $\frac{1}{2}$ mile from the mouth). The nets covered about one-fourth of the stream width. The downstream net captured all but a few of the fry collected. Twenty fry ranging from 0.9 to 1.1 inches were collected on April 28. Water temperature ranged from 45 to 48 F. The 0.9-inch fry still retained a yolk sac. The kokanee were very secretive. We could not observe them during daylight hours and caught none with seines, dip nets, or electroshocker. They moved downstream in large numbers only at night. On May 18 an overnight set of the two nets captured 212 fry which averaged about 1.0 inches (0.9 to 1.1 inches). Water temperature ranged from 48 to 54 F. Flow was about 25 cfs compared with about 2 cfs on April 28. Twenty-eight (13%) still had obvious yolk sacs. Apparently kokanee fry from Taylor Creek move downstream to Tahoe just before and shortly after absorption of the yolk sac, possibly immediately upon emergence.

Our trap also took large numbers of fry and fingerling Lahontan speckled dace (*Rhinichthys osculus robustus*) and brown trout. Lesser numbers of rainbow trout, Lahonton redside, Tahoe sucker (*Catostomus tahoensis*), and tui chub also were caught. Large brown trout are common in the deep, lower pools of this stream and probably prey heavily on fry moving through this area. Large rainbow spawners are migrating upstream and actively spawning at the same time kokanee fry are emerging from the gravel and moving downstream. Their effect on survival of kokanee fry is unknown.

Few young-of-the-year kokanee were collected from Lake Tahoe itself. On May 2, 1966, three kokanee fry (0.9 to 1.1 inches) were collected with a small sled trawl (Linn and Frantz, 1965) fished on the bottom in water 15 to 20 ft deep off the mouth of Taylor Creek. One 2.8-inch kokanee was collected in a 24-ft otter trawl in Agate Bay in November 1962 at a depth of about 150 ft. This was the only kokanee taken by this method, although 248, 10-minute trawls were made from October 1962 through September 1964. Almost all trawling was done at depths from 100 to 500 ft in Agate Bay and at South Tahoe. Occasional sampling in August and September of the shallow littoral zone also failed to capture kokanee.

Twenty-seven surface and midwater trawls, each of $\frac{1}{2}$ hr duration, were made at widely scattered locations around the lake from July through November 1964. We trawled at various depths from the surface to about 150 ft in water from 24 to 1,560 ft deep. Only four kokanee were collected: 3 fish, 1.3 to 1.6 inches, were taken on July 14 and one 2.5-inch fish on November 3. They were taken well offshore and below the surface at depths from 23 to 72 ft.

AGE AND GROWTH

We determined growth rates from scales taken from 242 kokanee captured in gill nets from 1961 through 1965 and in the fishery in 1967 and 1968. No scale samples from the 1963 year class were collected.

The body length-anterior scale radius relationship was determined for 174 gill-netted kokanee (Figure 3). Since the body-scale relationship was apparently linear, at least for kokanee from 8 to 17 inches, the back calculations to various ages was based on the direct proportion formula of Lee (Lagler, 1956; p. 155). The adjustment for size at scale formation was based on an examination of hatchery-reared kokanee fry rather than extrapolation of the body-scale regression line. The length at scale formation was 1.5 inches.

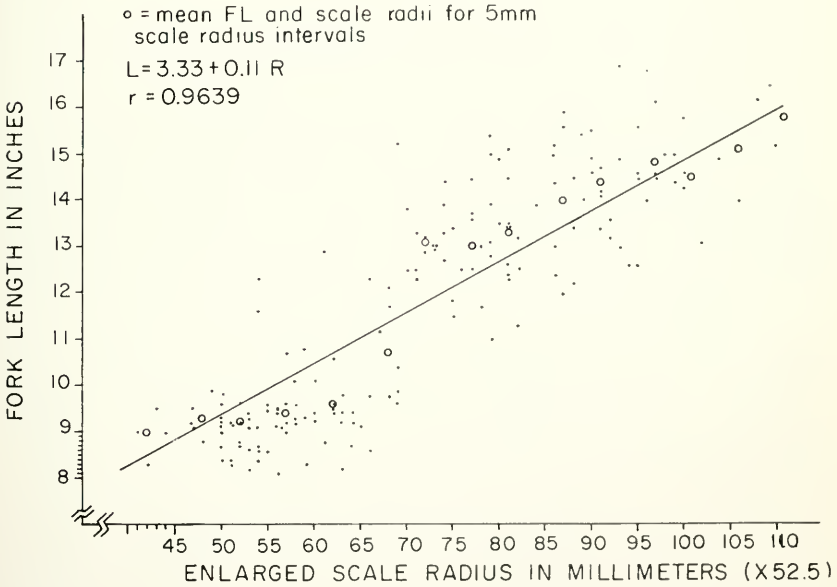


FIGURE 3. Body length-scale radius relationship of Lake Tahoe kokanee salmon. Upper graph represents data grouped by scale radius intervals, and lower graph data grouped by fork length intervals. N = 174.

The time of annulus formation could not be determined precisely from our data; however, April was apparently the critical month. The scales of all fish collected in May or later showed new growth for the calendar year beyond the last annulus, whereas scales from eight fish taken in January, February, and March did not show any new growth. Of 22 fish collected in April, new growth was apparent on the scales of 15, or 68%.

Although sparse, the data suggest that the growth rates in recent years have been generally greater than those in the later 1950's and early 1960's (Table 2). This increase occurred in spite of a corresponding increase in the kokanee population as indicated by the sizes of the Taylor Creek runs. However, growth data for several more years are needed to be certain of any definite trend.

TABLE 2—**Summary of Growth of Five Year Classes of Lake Tahoe Kokanee** *

Year class	Year of life			
	1	2	3	4
1961	4.3	8.6	12.4	15.2
	(153)	(153)	(83)	(2)
1962	4.7	9.1		
	(21)	(21)		
1964	4.4	10.8	15.6	18.6
	(13)	(13)	(13)	(1)
1965	4.8	8.9	14.8	
	(44)	(44)	(43)	
1966	5.5	12.2		
	(8)	(8)		

* Number of fish used in back calculations in parentheses.

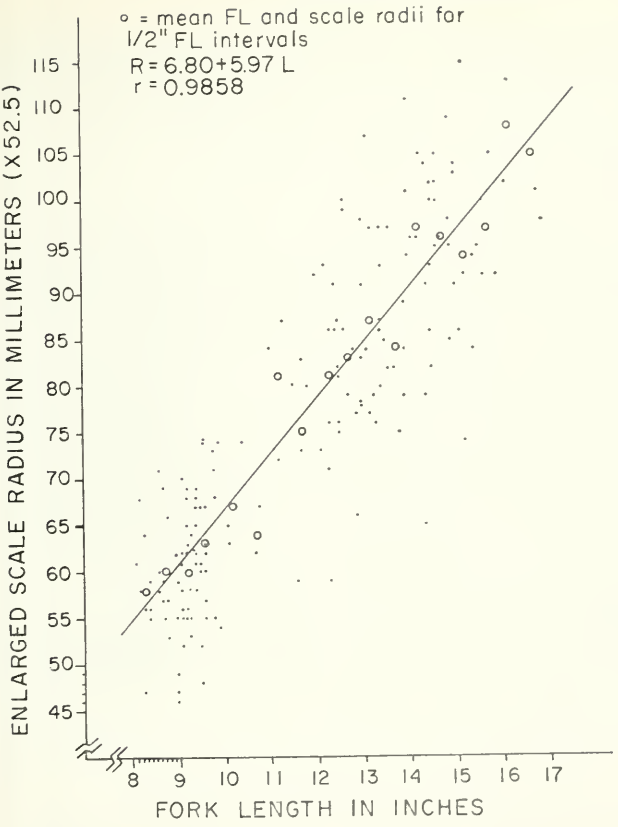
LENGTH-WEIGHT RELATIONSHIP

The length-weight relationship was calculated for 256 kokanee salmon collected from 1961 through 1965. Only fish collected from the lake itself were used. Plots of observed lengths and weights of males and females indicated no real differences, so they were combined. Fish were also combined without regard to state of maturity, method of collection, and time of collection. They were weighed to the nearest 0.01 lb.

TABLE 3—**Observed and Calculated Weights and Condition Factors of Lake Tahoe Kokanee Salmon**

Fork length*	No. fish	Observed weight, range	Observed weight, mean	Calculated weight	Condition factor, range	Condition factor, mean
4.7	1	---	0.04	0.05	---	41.1
6.2	1	---	0.11	0.11	---	42.0
8.2	9	0.22–0.28	0.25	0.25	38.5–52.7	44.2
8.7	10	0.26–0.33	0.30	0.30	40.9–48.6	44.8
9.2	35	0.30–0.41	0.34	0.35	39.0–52.7	43.8
9.7	20	0.33–0.44	0.38	0.41	37.3–45.7	43.1
10.2	3	0.48–0.53	0.50	0.47	41.1–46.6	44.8
10.7	3	0.51–0.61	0.56	0.55	42.8–49.8	45.9
11.2	3	0.68–0.86	0.75	0.62	51.2–64.6	54.3
11.7	5	0.70–0.84	0.76	0.71	43.7–52.6	48.1
12.2	11	0.80–1.00	0.88	0.80	44.1–52.4	48.2
12.7	13	0.84–1.10	0.95	0.90	40.1–52.5	47.3
13.2	21	0.94–1.27	1.09	1.00	41.8–52.9	47.5
13.7	11	1.00–1.39	1.20	1.11	39.8–51.8	45.3
14.2	12	1.04–1.43	1.26	1.24	37.9–52.1	44.4
14.7	18	1.20–1.46	1.35	1.37	38.6–46.9	42.8
15.2	13	1.28–1.67	1.49	1.51	37.9–47.6	42.8
15.7	16	1.53–1.83	1.66	1.66	39.8–46.9	42.9
16.2	21	1.64–1.93	1.74	1.82	39.0–44.6	41.4
16.7	9	1.71–2.36	1.90	1.98	35.9–48.9	40.2
17.2	8	1.77–2.29	1.99	2.16	36.0–43.5	39.6
17.7	7	1.86–2.50	2.19	2.35	33.0–43.6	39.5
18.2	1	---	2.16	2.55	---	37.0
18.7	1	---	2.80	2.76	---	41.5
19.2	2	2.50–2.58	2.54	2.98	36.4–37.0	36.7
19.7	1	---	3.47	3.21	---	46.1
20.7	1	---	3.23	3.71	---	35.4

* Midpoint of 0.5-inch intervals.



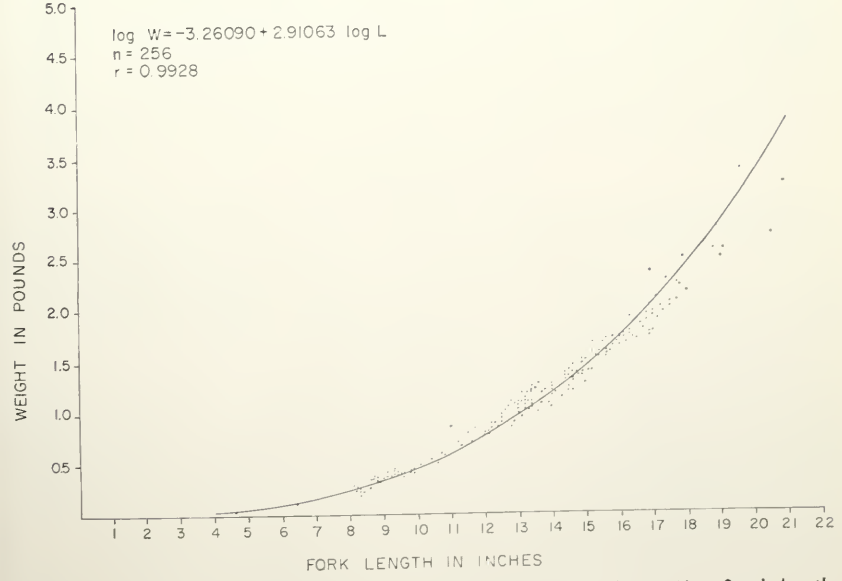


FIGURE 4. Length-weight relationship of Lake Tahoe kokanee salmon. Line fitted by the least squares method.

The length-weight relationship is described by the equation log W = −3.26090 + 2.91063 log L, or $W = 0.000548\ L^{2.91063}$ (Figure 4), where W is weight to the nearest 0.01 lb. and L is FL to the nearest 0.1 inches. Observed weights averaged for 0.5-inch length intervals corresponded closely with calculated weights (Table 3).

The condition factors $\left(C = \frac{W \times 10^5}{L^3}\right)$ of individual fish were grouped by 0.5-inch length intervals and averaged (Table 3). Condition factors tended to increase with size until fish reached about 13 inches and then declined. Virtually all of the fish over 13 inches were mature or ripe.

FOOD HABITS

We examined the stomach contents of 227 kokanee salmon ranging in length from 2.5 to 18.9 inches. Sixty-seven (29.5%) were empty and the remaining 160 contained primarily zooplankton (Table 4). Cladocerans, primarily *Daphnia pulex*, were found in 90 to 100% of the stomachs. A single species of copepod, *Epischura nevadensis*, was next in importance, occurring in about 15% of the stomachs. Midge larvae and pupae and surface insects occurred infrequently.

TABLE 4—**Percentage Frequency of Occurrence of Food in Stomachs of Lake Tahoe Kokanee Salmon by Four Size Groups, 1963 and 1964 Combined**

Item	Size groups (inches)				
	Under 5.0	5.0–9.9	10.0–14.9	15.0–19.9	All fish 2.5–18.9
Cladocera	100.0	93.2	89.0	100.0	**93.1**
Copepoda	50.0	15.9	26.0	14.6	**20.6**
Cladocera and copepoda	50.0	13.6	20.5	14.6	**17.5**
Midge larvae and pupae	----	2.3	1.4	2.4	**1.9**
Surface insects	----	2.3	4.1	----	**2.5**
Amphipoda	50.0	----	----	----	**0.6**
No. of stomachs	2	44	73	41	160

KOKANEE FISHERY

Kokanee salmon rarely entered the creels of Lake Tahoe anglers before 1967 (Cordone and Frantz, 1966*a*). In an intensive creel census by boat and at the Cave Rock Public Boat Landing from September 1960 through December 1963 we sampled only five kokanee (Cordone and Frantz, 1966*b*). These were all ripe fish taken off Taylor Creek. They remained scarce in the catch through 1966.

In May and June 1967, we received reports that kokanee were being caught in increasing numbers. In August 1967 an intensive kokanee fishery developed for the first time off the mouth of Taylor Creek (Figure 5). Most of the fish were caught approximately 80 to 100 ft below the surface. A few kokanee also were taken in Rubicon and Meeks bays at similar depths. This fishery lasted through September and marked the first time that anglers actually fished specifically for kokanee in Lake Tahoe.

In 1968 the first intensive fishing for kokanee occurred in the Meeks Bay-Sugar Pine Point area during June. This fishery remained relatively small throughout the summer, peaking in June and in early September. A much larger fishery again developed, in the Taylor Creek-Camp Richardson area late in June, with the greatest activity occurring during late July and early August. Both fisheries disappeared about the end of September. A few kokanee were landed off

FIGURE 5. Successful kokanee anglers off Taylor Creek, August 22, 1967. Photograph by R. D. Beland.

Cave Rock in May and June (Frantz, 1969), but this fishery was insignificant in relation to the other two. Also, a fishery of unknown magnitude occurred in October and November on kokanee spawning along the west shore between Sugar Pine Point and Sunnyside. In 1968, as in previous years, a downward movement of kokanee was observed as mid-summer approached. In May and June all of the kokanee were caught near the surface, but in July most were caught at depths of 50 to 75 feet; and in August at about 100 ft.

While at the surface, kokanee were caught with conventional topline gear, but later in the summer fishermen needed metal line to fish at the depths at which the kokanee occurred. Under both conditions the fishery was prosecuted entirely by trolling from boats.

From late June through September 1968, we conducted 22 creel surveys and/or use counts in the Meeks Bay and Taylor Creek areas. We estimated that 4,024 kokanee were caught from mid-July through September (95% C.I. = $\pm$1,386). This estimate is believed conservative as a disproportionately large number of days with bad weather were sampled. The small fishery on the Nevada side, and the Meeks Bay-Sugar Pine Point fishery in early June, were not sampled.

Although no creel censuses were conducted in 1967, we believe the fishing effort in 1968 was 5 to 10 times greater than in 1967, probably due to the late date (August) at which the fishing began in 1967. Success rates did not appear significantly different between the two years.

Fish size, however, was different between the two years. Twenty-nine of the kokanee caught in August 1967 averaged 18.5 inches. Fifteen of these were weighed and averaged 3.0 lb. In August 1968, 37 kokanee averaged 16.7 inches and 2.1 lb. The 1968 sample contained a slightly larger number of 2-year-old fish than the previous year; however, the difference in age composition was not great enough to account for difference in the average sizes of the fish.

DISCUSSION

The major summer fisheries developed in 1967 and 1968 when the kokanee were concentrated in schools, largely in the south and western parts of the lake, in preparation for spawning. Here their densities permitted successful angling by those trolling deep with heavy terminal tackle. As our sampling data indicate, they are widely scattered and nonschooling at other times of the year. The basic question now is whether or not this restricted fishery can be enlarged to include a greater portion of Tahoe's large limnetic zone and to include more of the colder months of the year when the surface orientation of kokanee would allow their capture by more conventional, light tackle. This would require, we believe, a substantial increase in the kokanee population.

Unfortunately, the sterility of Lake Tahoe (Goldman and Carter, 1965) might possibly limit the development of a kokanee fishery substantially larger than the existing one. Attempts to significantly increase their numbers may intensify intraspecific competition for a limited zooplankton supply (Lake Tahoe Fisheries Study, unpubl. data) and result in kokanee too small to be acceptable to the angler. However, there are some compensating factors. Although the density of the zooplankton is low, they occur as deep as 300- to 500-ft (Lake Tahoe Fisheries Study, unpubl. data). In addition, the recent establishment of *Mysis relicta* in Lake Tahoe (Frantz, 1969) may insert a previously unavailable energy source into the kokanee food chain.

It is possible that natural reproduction alone would increase the kokanee population to the point where either the fishery would expand in time and space, or where a substantial reduction in the average size of kokanee would preclude such an expansion. Taylor Creek is the only tributary that appears suitable for kokanee reproduction, but it has a limited carrying capacity (probably between 3,000 and 6,000 spawners). Lakeshore spawning is increasing, but again there may be definite limits imposed by available substrate type. Much of the littoral zone substrate is composed of sand and boulders. McKinney Bay may have the only suitable spawning grounds, although their precise extent and quality remain unknown.

RECOMMENDATIONS

Kokanee salmon are now thriving in Lake Tahoe and if managed properly should provide an important and large sport fishery. Hopefully, their numbers can increase and become abundant enough to be caught by topline anglers, a type of angler whose success has been very low (Cordone and Frantz, 1966*a*). Surplus eggs, sometimes in considerable numbers, can be collected from the Taylor Creek run. We recom-

mend that the egg take for Tahoe be limited to about 3 million. Subsequent growth, mortality, and contribution to the fishery of these fish and fish resulting from natural reproduction should be monitored carefully. Any necessary adjustments should be made in the number stocked to provide the highest possible sustained yield without depressing the growth rate. In this regard, the shoreline spawning areas should be completely surveyed and the size of the beach spawning population(s), and its (their) contribution to the fishery should be determined. Intragravel survival in both Taylor Creek and the beach spawning areas should be measured. The size composition of the spawning gravels and the quality of the intragravel water should be measured also.

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THE CARRYING CAPACITY FOR JUVENILE SALMONIDS IN SOME NORTHERN CALIFORNIA STREAMS[1]

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Standing crops of juvenile coho (silver) salmon (*Oncorhynchus kisutch*), steelhead rainbow trout (*Salmo gairdneri*), and coast cutthroat trout (*Salmo clarki*) were examined in seven coastal streams to define the natural carrying capacity of these streams, and to develop methods of population comparison and prediction which could be used to determine the effects of road construction and logging on salmon and trout production.

Biomass per unit of surface area was the best method of expressing carrying capacity, because biomass was better correlated with stream surface area than with other parameters tested. Volume of streambed sediments, total dissolved solids, alkalinity, and total phosphate in six streams were not satisfactory predictors of carrying capacity. Only living-space variables correlated significantly with biomass. Not all streams reached carrying capacity in the summer and salmonid biomass was highly variable. Even with 3 years of prelogging study, it would be difficult to attribute a change in carrying capacity under 50% to anything but natural variation.

INTRODUCTION

Standing crops of juvenile coho (silver) salmon, steelhead rainbow trout, and coast cutthroat trout were examined in seven coastal streams. The goals of this investigation were to define the natural salmonid carrying capacity of these streams, and to develop methods of population comparison and prediction which could be used to determine the effects of road construction and logging on salmon and trout production.

The most direct way to assess the impact of logging on anadromous salmonids is to compare numbers of juvenile outmigrants before and after logging. This method is generally impractical in California, because characteristic extreme seasonal fluctuations in streamflow make construction and maintenance costs of weirs and traps prohibitive (Burns, 1966). As an alternative, the juvenile carrying capacity of streams before and after logging was compared. Valid comparisons required a reliable, standardized sampling method. I reasoned that during minimum streamflow in the summer, juvenile salmonids would be at their greatest weight density (biomass per unit of living space), a density that would remain fairly constant from year to year and would be regulated by available living space. Any adverse effects of logging should decrease the stream's salmonid carrying capacity and be indicated by a decrease in the weight density of salmonids during summer. However, before this method was used, I had to test two hypotheses: (i) salmonid carrying capacity in coastal streams is attained during the summer, and (ii) the biomass of salmonids remains relatively con-

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stant from one summer to the next. The relationship of minimum streamflow and water quality to salmonid density was determined, since these variables also affect salmonid abundance and therefore carrying capacity.

Carrying capacity is defined as the greatest weight of fishes that a stream can naturally support during the period of least available habitat. It should be considered a mean value, around which populations fluctuate (Moyle, 1949). Spawning salmonids in coastal streams are thought to produce enough progeny to fill streams to carrying capacity. This assumption is supported by observations of high rates of emigration and mortality of fry shortly after emergence from the spawning bed (Shapovalov and Taft, 1954). Since a section of stream can accommodate only a limited number of territories, surplus fish are displaced (Allen, 1969). Displacement distributes fish to parts of the system remote from the spawning grounds, thus insuring that most of the area and productivity of the system is utilized. Even in the absence of excess fry production, receding summer streamflow limits habitat and practically insures that streams are filled to carrying capacity. Survival and growth of fishes in these streams are density dependent, or have density dependent components (McFadden, 1969). The stream's carrying capacity limits the number and weight of salmonid smolts ultimately produced.

METHODS

Sections of seven streams were studied during the summers of 1966 through 1969. The streams are located in the coastal redwood (*Sequoia sempervirens*) belt between Crescent City and Fort Bragg, California. Three northern streams, Bummer Lake Creek, Godwood Creek, and South Fork Yager Creek, were in virgin, old growth forests (never logged) and four southern streams, North Fork James Creek, Little North Fork Noyo River, North Fork Caspar Creek and South Fork Caspar Creek, were in second-growth forests (logged about 100 years ago). Four of these streams (Bummer Lake Creek, South Fork Yager Creek, Little North Fork Noyo River, and South Fork Caspar Creek) were logged by 1968 (Burns, 1970); however, this report considers only prelogging conditions (Table 1). Postlogging conditions are the subject of a future report (James W. Burns, MS). Only one stream had been recently logged (North Fork James Creek) and logging was completed there in 1962. This stream was surveyed once. Unlogged streams (Godwood Creek, an upstream section of South Fork Yager Creek, and North Fork Caspar Creek) were studied for 3 years. More detailed descriptions of the streams are given by Burns (1970) and Fredric R. Kopperdahl, James W. Burns and Gary E. Smith (MS). Fishing pressure for juvenile salmonids on these streams was negligible.

Stream dimensions were determined by standard sampling procedures (Welch, 1948 and Lagler, 1956) using permanent transect stations. The number of transect stations ranged from 30 in stream sections less than 1 km long, to 101 in longer sections. Fish were captured with a battery-powered DC back-pack shocker, and populations estimated by the Petersen single census mark and recovery method (Davis, 1964) or by the removal method (Seber and LeCren, 1967). Age classes of trout were separated by length frequency methods. Fish less than 1 year

TABLE 1—**Habitat Dimensions and Teleost Biomass in Seven Northern California Streams**

	Survey date	Dimensions of sections at time of survey						Absolute biomass, kg (lb)				
		Discharge, m^3/sec (cfs)	Length, km (mi)	Surface area, hectares (acres)			Volume, m^3 (acre-ft)	Coho salmon	Trout	Total salmonids	Non-salmonids	Total teleosts
				Pools	Riffles	Total						
Bummer Lake Cr., Del Norte County	Sept. 1967	0.015 (0.521)	1.524 (0.521)	0.459 (1.135)	0.270 (0.667)	0.729 (1.802)	1,444 (1.171)	1.12 (2.46)	28.90* (63.71)	30.02 (66.17)	0.98‡ (2.15)	31.00 (68.32)
Godwood Cr., Humboldt County	July 1967	0.036 (1.270)	1.098 (0.682)	0.214 (0.529)	0.111 (0.273)	0.325 (0.802)	445 (0.361)	3.56 (7.84)	1.86* (4.09)	5.42 (11.93)	0.17§ (0.37)	5.59 (12.30)
S. Fk. Yager Cr., Humboldt County	Aug. 1967	0.017 (0.598)	1.119 (0.695)	0.420 (1.038)	0.163 (0.403)	0.583 (1.441)	752 (0.610)	---- ----	25.62† (56.48)	25.62 (56.48)	0.68‡ (1.51)	26.30 (57.99)
N. Fk. James Cr., Mendocino County	Oct. 1966	0.003 (0.100)	0.039 (0.024)	0.005 (0.012)	0.003 (0.007)	0.008 (0.019)	10 (0.008)	---- ----	0.52† (1.15)	0.52 (1.15)	0.09‡ (0.20)	0.61 (1.35)
Little N. Fk. Noyo R., Mendocino County	Oct. 1966	0.002 (0.077)	0.399 (0.248)	0.041 (0.102)	0.019 (0.048)	0.060 (0.150)	92 (0.075)	1.26 (2.77)	0.22† (0.49)	1.48 (3.26)	0.10‡ (0.21)	1.58 (3.47)
N. Fk. Caspar Cr., Mendocino County	June 1967	0.012 (0.415)	2.451 (1.523)	0.263 (0.650)	0.215 (0.531)	0.478 (1.181)	291 (0.236)	0.84 (1.86)	5.21† (11.48)	6.05 (13.34)	---- ----	6.05 (13.34)
S. Fk. Caspar Cr., Mendocino County	June 1967	0.013 (0.447)	3.092 (1.921)	0.295 (0.730)	0.308 (0.760)	0.603 (1.490)	367 (0.298)	9.59 (21.15)	13.31† (29.34)	22.90 (50.49)	0.15# (0.32)	23.05 (50.81)

* Steelhead rainbow trout (*Salmo gairdneri*) and coast cutthroat trout (*Salmo clarki*).
† Steelhead rainbow trout.
‡ Sculpin (*Cottus spp.*).
§ Sculpin and threespine stickleback (*Gasterosteus aculeatus*).
# Threespine stickleback.

old were designated as Age +, and yearling and older fish were lumped as a single group, Age 1+. Coho salmon juveniles were also combined as a single group, Age +, since few spend more than 1 year in stream residence. Biomass was determined by multiplying mean individual weight by the population estimate for each species. Population estimates were presented in two forms: (i) absolute, referring to the estimated population of fish in the stream section (e.g., kilograms or numbers), and (ii) relative, referring to the population of fish per unit of living space (e.g., kilograms per hectare or number per square meter).

RESULTS AND DISCUSSION

Methods of Expressing Carrying Capacity

Carrying capacity is expressed either as the number of fish in the population, or more commonly, as the total weight of the population (biomass). Living space is also considered when measuring carrying capacity, since changes in biomass may be due to changes in available habitat. Living space parameters include stream surface area, volume, length, and flow. To determine which variables best expressed relative biomass, correlation coefficients for fish biomass and each of these living space parameters were calculated. Since these seven streams varied considerably in the length of stream surveyed and in their biomass (Table 1), I thought that some unmeasured factors could influence the correlations tested. Therefore, correlation coefficients for both the seven streams and a single stream were calculated (Table 2), thereby eliminating some of the unmeasured factors. The best correlation for the seven streams was absolute biomass with surface area (Table 3). For North Fork Caspar Creek, biomass per surface area was also superior, with streamflow also having a significant correlation with absolute biomass. These results pointed to kilograms per hectare or pounds per acre as superior to other expressions of biomass. Coho production in Oregon streams also correlated more strongly with available stream area than with other stream parameters (Mason and Chapman, 1965).

Changes in Biomass

Salmonid biomass in the unlogged streams changed considerably during the study. North Fork Caspar Creek's mean biomass of salmonids was 5.56 kg (Table 2). The 95% confidence limits were ±27.5% of the mean. The confidence limits of the mean kilogram per hectare were ±16.9% ($\bar{y} = 15.54$). The mean in South Fork Yager Creek was 8.67 kg (Table 4), with 95% confidence limits of ±13.0%. The confidence limits of the mean kilograms per hectare were ±47.8% ($\bar{y} = 34.59$). Changes in biomass in Godwood Creek were greater than in the other two streams (Table 5). The mean biomass of salmonids was 4.06 kg, with 95% confidence limits of ±75.2%. The confidence interval of the mean kilograms per hectare were ±81.2% ($\bar{y} = 12.54$).

Weakness in the Biomass/Surface Area Expression

Density expressions of biomass (kg/ha) did not reflect well the real changes in total fish populations. They commonly increased in late summer when the total biomass actually decreased. Absolute biomass in North Fork Caspar Creek, for example, usually decreased as the stream's surface area decreased (Table 2). Relative biomass increased,

TABLE 2—**Stream Dimensions and Teleost Biomass in North Fork Caspar Creek, Mendocino County**

Survey date	Discharge, m^3/sec (cfs)	Stream dimensions at time of survey					Absolute biomass, kg (lb)			Relative biomass
		length, km (mi)	Surface area, hectares (acres)			Volume, m^3 (acre-ft)	Coho salmon	Steelhead rainbow trout	Total salmonids	Total salmonids, kg/ha (lb/acre)
			Pools	Riffles	Total					
June 1967	0.012 (0.415)	2.451 (1.523)	0.263 (0.650)	0.215 (0.531)	0.478 (1.181)	291 (0.236)	0.84 (1.86)	5.21 (11.48)	6.05 (13.34)	12.64 (11.29)
Oct. 1967	0.007 (0.237)	2.326 (1.445)	0.195 (0.482)	0.195 (0.481)	0.390 (0.963)	178 (0.144)	0.57 (1.26)	5.70 (12.57)	6.27 (13.83)	16.08 (14.36)
June 1968	0.007 (0.242)	2.458 (1.527)	0.191 (0.471)	0.169 (0.417)	0.360 (0.888)	219 (0.178)	0.45 (0.99)	4.18 (9.21)	4.63 (10.20)	12.87 (11.49)
Oct. 1968	0.001 (0.038)	1.984 (1.233)	0.163 (0.403)	0.067 (0.165)	0.230 (0.568)	105 (0.085)	0.44 (0.98)	3.32 (7.32)	3.76 (8.30)	16.36 (14.61)
June 1969	0.013 (0.446)	2.458 (1.527)	0.242 (0.598)	0.252 (0.623)	0.494 (1.221)	301 (0.244)	2.99 (6.59)	4.85 (10.69)	7.84 (17.28)	15.85 (14.15)
Oct. 1969	0.001 (0.044)	1.975 (1.227)	0.148 (0.366)	0.099 (0.244)	0.247 (0.610)	150 (0.122)	2.00 (4.40)	2.79 (6.16)	4.79 (10.56)	19.39 (17.31)

TABLE 3—**Correlation Coefficients for Living Space Parameters and Biomass**

Variables tested	Correlation coefficient	Statistically significant at 5% level
Seven northern California streams		
Stream surface area (ha) vs. salmonid biomass (kg)	0.898	yes
Stream surface area (ha) vs. teleost biomass (kg)	0.895	yes
Stream volume (m^3) vs. salmonid biomass (kg)	0.837	yes
Stream volume (m^3) vs. teleost biomass (kg)	0.844	yes
Streamflow (m^3/sec) vs. salmonid biomass (kg/km)	0.003	no
Streamflow (m^3/sec) vs. teleost biomass (kg/km)	0.020	no
North Fork Caspar Creek, Mendocino County		
Wetted stream length (m) vs. salmonid biomass (kg)	0.656	no
Stream surface area (ha) vs. salmonid biomass (kg)	0.868	yes
Stream volume (m^3) vs. salmonid biomass (kg)	0.790	no
Streamflow (m^3/sec) vs. salmonid biomass (kg)	0.836	yes
Streamflow (m^3/sec) vs. salmonid biomass (kg)	0.622	no

however, because the fish were forced into a smaller area. Steelhead may have adjusted to greater population densities by reducing territory size. Accommodation by steelhead has been reported from British Columbia streams (Hartman, 1965). Another possible explanation for the increase is that the stream was not at carrying capacity in June because of low fry production resulting from small spawning escapements. Decreasing living space may have brought these fish to densities at or near the carrying capacity in October. To describe accurately changes in fish populations and carrying capacity it is best to present the absolute along with the relative values.

Carrying Capacity Studies

Salmonid biomass in Godwood Creek was exceptionally low, ranging from 16.68 kg/ha in 1967 to 8.48 in 1969 (Table 5). Prairie Creek, to which Godwood Creek is a tributary, had a salmonid biomass of 21.95 kg/ha in 1969, suggesting that Godwood Creek probably wasn't at carrying capacity. Low population densities in Godwood Creek in 1968 and 1969 apparently reduced competition, for fish attained greater average lengths than in 1967, when densities were greater (Table 6). Increased growth, however, apparently did not compensate for lowered density and carrying capacity was not reached in 1968 and 1969. To test if Godwood Creek was at carrying capacity in 1969, I transplanted the salmonids captured in Prairie Creek in July into a 366-m section of Godwood Creek in sufficient numbers to increase the biomass to 27.98 kg/ha. Two months later the same section of Godwood Creek was censused to determine if the biomass had remained above the July 1969 value of 7.36 kg/ha. It was 18.08 kg/ha at the second census. This experiment demonstrated that the stream had been below carrying capacity before transplanting the Prairie Creek fish. There were no obvious reasons for the low number of salmonids in 1968 and 1969, except that young-of-the-year coho were exceptionally scarce then, suggesting that the spawning run had not seeded the stream to carrying capacity. There were no significant changes in spawning bed sediments (Burns, 1970) to explain reduced survival of incubating embryos and fry.

TABLE 4—Stream Dimensions and Teleost Biomass in South Fork Yager Creek, Humboldt County

Survey date	Discharge, m³/sec (cfs)	Stream dimensions at time of survey					Absolute biomass, kg(lb)		Relative biomass
		Length, km(mi)	Surface area, hectares (acres)			Volume, m³(acre-ft)	Steelhead rainbow trout	Non-salmonids*	Total salmonids, kg/ha (lb/acre)
			Pools	Riffles	Total				
Aug. 1967	0.017 (0.598)	0.560 (0.348)	0.205 (0.506)	0.068 (0.168)	0.273 (0.674)	374 (0.303)	8.80 (19.39)	0.02 (0.05)	32.22 (28.77)
Aug. 1968	0.015 (0.527)	0.560 (0.348)	0.110 (0.271)	0.105 (0.260)	0.215 (0.531)	229 (0.186)	9.05 (19.95)		42.08 (37.57)
Aug. 1969	0.020 (0.719)	0.560 (0.348)	0.192 (0.474)	0.086 (0.213)	0.278 (0.687)	381 (0.309)	8.18 (18.03)		29.39 (26.24)

* Sculpin (*Cottus* spp.).

TABLE 5—Stream Dimensions and Teleost Biomass in Godwood Creek, Humboldt County

Survey date	Discharge, m³/sec (cfs)	Stream dimensions at time of survey					Absolute biomass, kg (lb)				Relative biomass
		Length, km(mi)	Surface area, hectares (acres)			Volume, m³(acre-ft)	Coho salmon	Trout*	Total salmonids	Non-salmonids†	Total salmonids, kg/ha (lb/acre)
			Pools	Riffles	Total						
July 1967	0.036 (1.270)	1.098 (0.682)	0.214 (0.529)	0.110 (0.273)	0.324 (0.802)	445 (0.361)	3.56 (7.84)	1.86 (4.09)	5.42 (11.93)	0.17 (0.37)	16.68 (14.88)
July 1968	0.029 (1.039)	1.098 (0.682)	0.157 (0.388)	0.150 (0.372)	0.307 (0.760)	375 (0.304)	2.32 (5.12)	1.51 (3.33)	3.83 (8.45)	0.02 (0.05)	12.45 (11.12)
July 1969	0.031 (1.080)	1.098 (0.682)	0.228 (0.564)	0.123 (0.304)	0.351 (0.868)	428 (0.347)	1.20 (2.64)	1.78 (3.93)	2.98 (6.57)	0.03 (0.07)	8.48 (7.57)

* Steelhead rainbow trout (*Salmo gairdneri*) and coast cutthroat trout (*Salmo clarki*).
† Sculpin (*Cottus* spp.) and threespine stickleback (*Gasterosteus aculeatus*).

TABLE 6—Population Densities, Mean Fork Lengths, and Absolute Numbers of Salmonids in Godwood Creek, Humboldt County *

Survey date	Steelhead rainbow and coast cutthroat trout						Coho salmon		
	Young of the year			Yearling and older					
	No. /m² (kg/ha)	Mean fork length, mm	Number	No. /m² (kg/ha)	Mean fork length, mm	Number	No. /m² (kg/ha)	Mean fork length, mm	Number
July 1967	0.14 (1.40)	41 (40–42)	455 (374–536)	0.04 (4.32)	97 (90–104)	121 (72–170)	0.37 (10.96)	55 (54–56)	1,186 (1,051–1,321)
July 1968	0.11 (1.17)	45 (44–46)	325 (274–376)	0.03 (3.74)	102 (97–107)	88 (65–111)	0.31 (7.56)	56 (55–57)	961 (922–998)
July 1969	0.07 (1.34)	51 (53–55)	248 (198–299)	0.02 (3.73)	105 (101–109)	88 (64–111)	0.10 (3.41)	64 (63–65)	352 (338–366)

* 95% confidence intervals in parentheses unless indicated otherwise.

TABLE 7—Population Densities, Mean Fork Lengths, and Absolute Numbers of Steelhead Rainbow Trout in South Fork Yager Creek, Humboldt County *

Survey date	Young-of-the-year			Yearling and older		
	No./m² (kg/ha)	Mean fork length, mm	Number	No./m² (kg/ha)	Mean fork length, mm	Number
Aug. 1967	0.60 (10.22)	46 (45–48)	1,641 (1,470–1,812)	0.11 (22.01)	117 (111–124)	299 (193–405)
Aug. 1968	0.92 (18.35)	54 (53–56)	1,973 (1,695–2,251)	0.13 (23.77)	115 (110–119)	284 (208–360)
Aug. 1969	0.86 (11.14)	47 (46–48)	2,385 (2,244–2,526)	0.10 (18.27)	115 (112–119)	289 (268–310)

* 95% confidence intervals in parentheses unless indicated otherwise.

Predation by oligochaete worms may have contributed to low survival, since Briggs (1953) found that the average mortality in Godwood Creek was about 56% and sometimes as high as 100% in salmon redds infested with oligochaetes. Oligochaetes were abundant in the benthos samples taken in July 1967; however, benthos was not examined in 1968 and 1969, when coho populations were lowest. Briggs also indicated that the spawning runs in Godwood Creek were usually small, with only about seven redds resulting from coho spawning in 3.2 km of stream. This experiment shows that artificially seeding streams with fry could bring them up to carrying capacity.

Yearling-and-older steelhead in South Fork Yager Creek were similar in population density and average length in all years (Table 7). Age + steelhead, on the other hand, attained the greatest average length in 1968, when population density for this age group was greatest. In 1967 and 1969, densities were less and mean lengths were shorter, indicating that either carrying capacity changed or that the stream was not at carrying capacity in these 2 years.

Except for the seasonal increase that usually accompanies a decrease in surface area, the density of salmonids in North Fork Caspar Creek was similar in 1967 and 1968 (Table 8). In 1969, however, the density increased 22% over the 1967–68 average. Coho were scarce in 1967–68 and then became abundant in 1969. Apparently interspecific competition was less influential than intraspecific competition in determining this stream's carrying capacity. These observations support the contentions of Nilsson (1956), Hartman (1965), and Fraser (1969) that two or more species use the habitat more efficiently than does one species alone. The similarity of biomasses in 1967 and 1968 suggests that the stream was at or near carrying capacity for the existing species combination. The change in species ratio apparently increased the carrying capacity in 1969. Territorially in stream salmonids is food-linked; when food is abundant, aggression decreases and territories become smaller (Chapman, 1966). A higher population density could therefore result from an increased food supply. An increase in food did not occur in North Fork Caspar Creek, since the biomass of benthos was similar in all years of study (James W. Burns and Gary E. Smith, MS).

Young-of-the-year salmonids in North Fork Caspar Creek in June were largest when stock densities were lowest, suggesting a density dependent relationship (Table 8). Growth increments for salmonids in North Fork Caspar Creek from June to October, however, did not show any trend and therefore did not support a hypothesis of density dependent growth. Over-summer mortality did not indicate density dependence either. Decreasing availability of living space caused the greatest mortality, with total mortality highest in the summer of lowest streamflow. Mortality of Age + steelhead from June to October averaged 73% (range 71 to 80%). Mortality of Age I or older steelhead averaged 44% (range 6 to 66%). For Age + coho, average mortality was 58% (range 46 to 61%).

North Fork Caspar Creek was relatively unproductive. Besides supporting a low biomass per surface area of salmonids, it had low summer production (Table 9). Production of salmonids from June to October ranged from 0.29 to 0.38 g/m^2/month. This was considerably

TABLE 8—**Population Densities, Mean Fork Lengths, and Absolute Numbers of Salmonids in North Casper Creek, Mendocino County** *

Survey date	Steelhead rainbow trout						Coho salmon		
	Young-of-the-year			Yearling and older					
	No./m² (kg/ha)	Mean fork length, mm	Number	No. /m² (kg/ha)	Mean fork length, mm	Number	No. /m² (kg/ha)	Mean fork length, mm	Number
June 1967	1.37 (9.59)	39 (38–40)	6 558 (6 370–6,746)	0.02 (1.30)	77 (73–80)	93 (3–196)	0.07 (1.76)	54 (54–60)	313 (261–365)
Oct. 1967	0.52 (10.33)	54 (52–55)	2,015 (1,897–2,133)	0.02 (4.29)	123 (84–163)	69 (19–119)	0.03 (1.47)	71 (69–73)	122 (110–134)
June 1968	1.61 (9.68)	38 (37–39)	5 801 (5,723–5,879)	0.02 (1.94)	86 (80–93)	82 (41–113)	0.10 (1.26)	47 (46–48)	359 (335–381)
Oct. 1968	0.51 (8.66)	51 (50–52)	1,172 (1,107–1,237)	0.03 (5.77)	117 (109–124)	77 (54–100)	0.08 (1.94)	52 (47–57)	194 (185–203)
June 1969	0.81 (5.67)	40 (39–41)	4,005 (3,896–4,114)	0.04 (4.14)	92 (86–97)	211 (158–264)	0.55 (6.41)	45 (44–46)	2,724 (2,675–2,771)
Oct. 1969	0.47 (6.98)	52 (51–53)	1,151 (1,101–1,201)	0.03 (4.34)	108 (100–115)	71 (46–96)	0.45 (8.08)	53 (52–54)	1,105 (1,079–1,127)

* 95% confidence intervals in parentheses unless indicated otherwise.

TABLE 9—**Production of Salmonids in North Fork Caspar Creek, Mendocino County, California**

Period	Steelhead rainbow trout				Coho salmon		Total	
	Young of the year		Yearling and older		Young of the year			
	g/m²/month	g/month	g/m²/month	g/month	g/m²/month	g/month	g/m²/month	g/month
June to Oct. 1967	0.2627	1,140.0	0.0860	373.1	0.0270	117.0	0.3757	1,630.1
June to Oct. 1968	0.2616	770.6	0.0662	194.9	0.0262	77.0	0.3540	1.042.5
June to Oct. 1969	0.1358	503.2	0.0543	201.4	0.0966	357.9	0.2867	1,062.5

lower than the coho production of 0.56 g/m^2/month reported for the same season for Oregon's salmonid streams (Chapman, 1965).

Relationships of Physical-Chemical Factors to Carrying Capacities

The relationship of water chemistry and morphoedaphic characteristics of lakes to fish production and standing crop have been investigated by Moyle (1946, 1956), Hayes and Anthony (1964), and Ryder (1965); however, little is known of the relationships of these factors to the carrying capacity of streams. A positive correlation between brown trout *(S. trutta)* biomass and conductivity in six Pennsylvania streams was reported by McFadden and Cooper (1962); however, this relationship was not statistically significant. LeCren (1969) found no apparent correlation between brown trout and Atlantic salmon *(S. salar)* production and calcium content of English streams. I failed to find any significant correlations between relative biomass and either total dissolved solids, total phosphate, or total alkalinity (Table 10). In addition, biomass was not significantly correlated with the volume of fine sediments in the streambed.

CONCLUSIONS

Biomass per unit of surface area was an acceptable method of expressing carrying capacity in small coastal streams. This expression did not always reflect trends in the absolute biomass, however. If lower surface area accompanied lower biomass, the kilograms per hectare of salmonids could remain the same or even increase, leading to erroneous conclusions about changes in fish populations. For this reason, it is necessary to include an absolute value when making such comparisons. The absolute value could be the number of fish in each age class for each species. The two values compliment each other; one considers changes in living space, while both reflect changes in fish abundance.

The hypotheses that streams reach carrying capacity in the summer, and that biomass per unit of living space is constant from 1 year to the next, must be rejected. Because of natural variation, comparing biomass from 1 summer month or year to the next was adequate for indicating gross changes only. In Godwood Creek the maximum change in relative biomass from the first to the third year was 49% and in North Fork Caspar Creek, the change from June to October of the same year

TABLE 10—**Salmonid Biomasses and Some Physical and Chemical Parameters of Six Streams**

Stream	Salmonid biomass, kg/ha	Total dissolved solids, ppm*	Total alkalinity, ppm*	Total phosphate, ppm*	Percentage mean volume of sediments smaller than 0.8 mm diameter†
Bummer Lake Cr.	41.13	57	26	0.30	10.2
Godwood Cr.	16.67	80	30	0.45	17.3
S. Fk. Yager Cr.	43.90	109	56	0.43	16.4
Little N. Fk. Noyo R.	24.35	112	51	0.36	20.0
N. Fk. Caspar Cr.	12.64	124	57	0.34	18.4
S. Fk. Caspar Cr.	37.95	149	68	0.43	20.6

* Value from Fredric R. Kopperdahl, James W. Burns, and Gary E. Smith (MS).
† Values from Burns (1970).

was as much as 25%. The 95% confidence limits of the mean kilograms per hectare of salmonids in South Fork Yager Creek were ±48% of the mean. These results demonstrate that even with 3 years of prelogging measurements it would be difficult to attribute a change in carrying capacity to anything but natural variation unless the change exceeded about 50%. These extremes in natural variation are probably due to variable spawning escapement and, in the case of juvenile steelhead, to variable time spent in fresh water.

It does not appear that physical and chemical factors will prove to be useful factors for predicting carrying capacity, as only living space variables correlated significantly with biomass.

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SOME INFLUENCES OF TEMPERATURE ON THE DEVELOPMENT OF THE GRUNION *LEURESTHES TENUIS* (AYRES)[1]

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The effect of temperature upon the development of the grunion, was studied throughout the spawning season of the fish. The viable range for hatching was determined to be 14.0–28.5 C. Developmental temperature coefficients were calculated for hatching, lens formation, eye pigmentation, heart beating, and embryonic axis formation. These were equal for all of the characteristics, but two distinct ones were found within the viable range, —0.0613 from 14.0–23.0 C and —0.0113 from 23.0–28.5 C. A temperature coefficient for maintenance of —0.0221 was determined for the grunion during the period after it is ready to hatch but before it is freed from the sand. The maximum percentage of hatching was close to 100 between 16.0–27.0 C but dropped off rapidly outside this thermal range. The average length at hatching was not influenced by the degree-hours incubated. The growth rate of larvae at 18.0 C post-hatching was not influenced by the temperature at which they were incubated.

INTRODUCTION

The reproductive habits of the grunion have been studied by Walker (1952). He found that in southern California grunion spawn on the beach just after high tide on descending spring tides from late February or early March through late August or early September. The eggs remain in the sand until they are liberated by the next tide high enough to reach them; this may require only 10 days or up to a month, depending on the height of the tides and when the eggs were spawned. Walker also showed that eggs may develop to the point of hatching but will not do so until they are agitated (i.e. wave action).

If the grunion had a constant and continuous increase in its developmental rate with respect to temperature, the eggs would develop with increasing rapidity due to the increasing ambient temperature as the season progressed. The late spawned eggs then would have to spend a longer time maintaining themselves in the sand, until they could hatch. Furthermore, when summer spawned larvae entered the water, their metabolic rate would be higher than that of spring spawned individuals, but their yolk reserves would be lower. Since the larvae, after hatching, are dependent upon their yolk reserves until they can capture food, it seems reasonable that a fish with a mechanism for conserving yolk to use during this critical period would have a selective advantage over one that did not have such a mechanism. One possible adaptation to this situation would have been for late-spawned eggs to have a slower rate of increase in developmental rate with respect to tempera-

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ture. To test this possibility, eggs were collected from various runs throughout the spawning season and incubated at different temperatures within their viable limits determined in this study.

METHODS AND MATERIALS

Grunion were collected on the beach at La Jolla, California, during their bimonthly runs, from the middle of February to the end of August 1968. Gametes collected from the spawning fish were mixed in a half-liter plastic container holding 25 cc of sea water. After about 15 min the excess milt was poured off, and fresh sea water was added. Approximately 1 hr elapsed following the last egg collection before placing them in the appropriate incubation chambers. Eggs were incubated in fine gravel (1–2 mm diameter) with aerated sea water, which was changed every 2 or 3 days, dripping through it (Figure 1). No

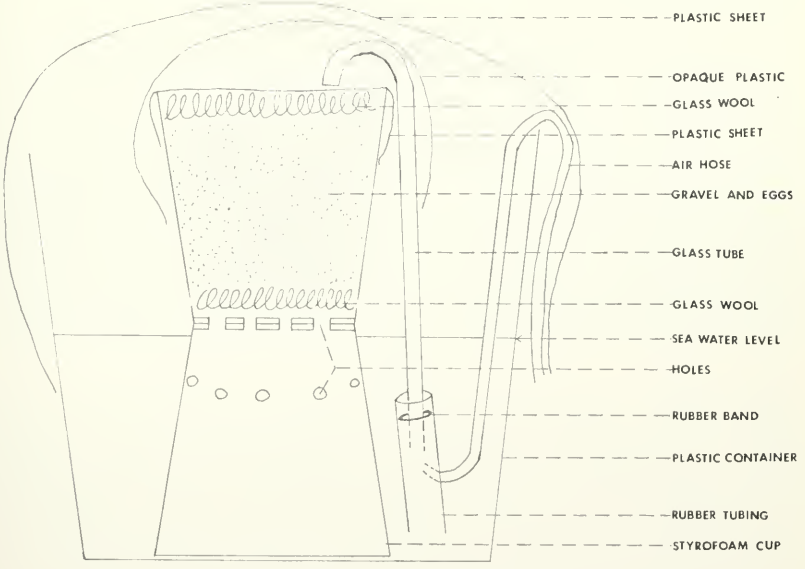

FIGURE 1. Chamber used to incubate grunion eggs.

attempt was made to simulate tidal changes. The incubation chamber was covered with a plastic sheet to diminish evaporation. All eggs were incubated in the dark in order to prevent any variability due to light. The incubation chambers were placed in thermostatically controlled water baths which maintained the following temperatures: (± 0.25 C): 13.5, 14.5, 14.9, 15.5, 18.0, 20.0, 23.0, 24.0, 25.0, 26.0, 26.5, 26.7, 27.0, 27.6, 28.0, 28.5, and 29.0 C. Due to lack of equipment, eggs from each collection were not incubated at every temperature.

At about 24 hr intervals, samples of approximately 50 eggs were removed from each chamber and examined for their state of development. The criteria recorded were embryonic axis formation, heart beating, eye pigmentation, lens formation, and hatching. A characteristic was considered to first appear when 50% of the sample showed it. Eggs

were left in the incubation chambers beyond the time they were capable of hatching in order to determine the length of time they could remain in the gravel, with respect to temperature, and still be capable of hatching.

The temperature coefficient for maintenance was calculated on the basis of the time from which 50% of the eggs first could hatch upon agitation, to when, after remaining in the sand for various periods, at least 50% of them could still hatch when agitated in sea water. The temperature coefficients for development and maintenance were determined by calculating the least square lines. In this paper, the term temperature coefficient is used to describe these coefficients calculated in this manner. It does not apply to Q_{10} values which were calculated differently.

The Q_{10} values for development were determined at 2 degree intervals over the range of 14.0–22.0 C. The van't Hoff formula, as described by Giese (1962), was used for these calculations:

$$\log Q_{10} = \frac{10}{t_2 - t_1} \qquad \log \frac{K_2}{K_1}.$$

In this formula K_2 is the rate at temperature t_2, and K_1 is the rate at t_1.

In order to assess the effect of incubation temperature upon future larval growth rates, a group of larvae from incubation temperatures of 15.5, 16.0, 23.0, 26.0, and 28.0 C were reared for 45 days after hatching. This was done in five 15 gallon aquaria sitting in a partitioned water table. The water temperature was maintained at 18.0 C, to which the larvae were allowed to acclimate before release into the aquaria. Brine shrimp, *Artemia salina,* nauplii were used for food.

RESULTS

Temperature tolerance limits for hatching were 14.0–28.5 C. Two distinct developmental temperature coefficients were found (Figure 2); these were in the ranges of 14.0–23.0 and 23.0–28.5 C. The time required for any of the examined characteristics (Table 1), to first occur or be detected at any one temperature, did not appreciably vary throughout the spawning season. The developmental temperature coefficients of the different characteristics, when tested by means of a covariance analysis, were statistically indistinguishable (14.0–23.0 C, $F(4, 49)df = 2.08$, $p<0.1$; 23.0–28.5 C, $F(4, 52)df = 2.09$, $p<0.1$).

TABLE 1—**Temperature Coefficients Throughout the Viable Range for Development**

Characteristic	Temperature coefficients for development	
	Temperature range 14.0–23.0 C	Temperature range 23.0–28.5 C
Hatching	−0.0656	−0.0199
Lens formation	−0.0678	−0.0010
Eye pigmentation	−0.0559	−0.0023
Heart beating	−0.0641	−0.0117
Embryonic axis formation	−0.0570	−0.0290

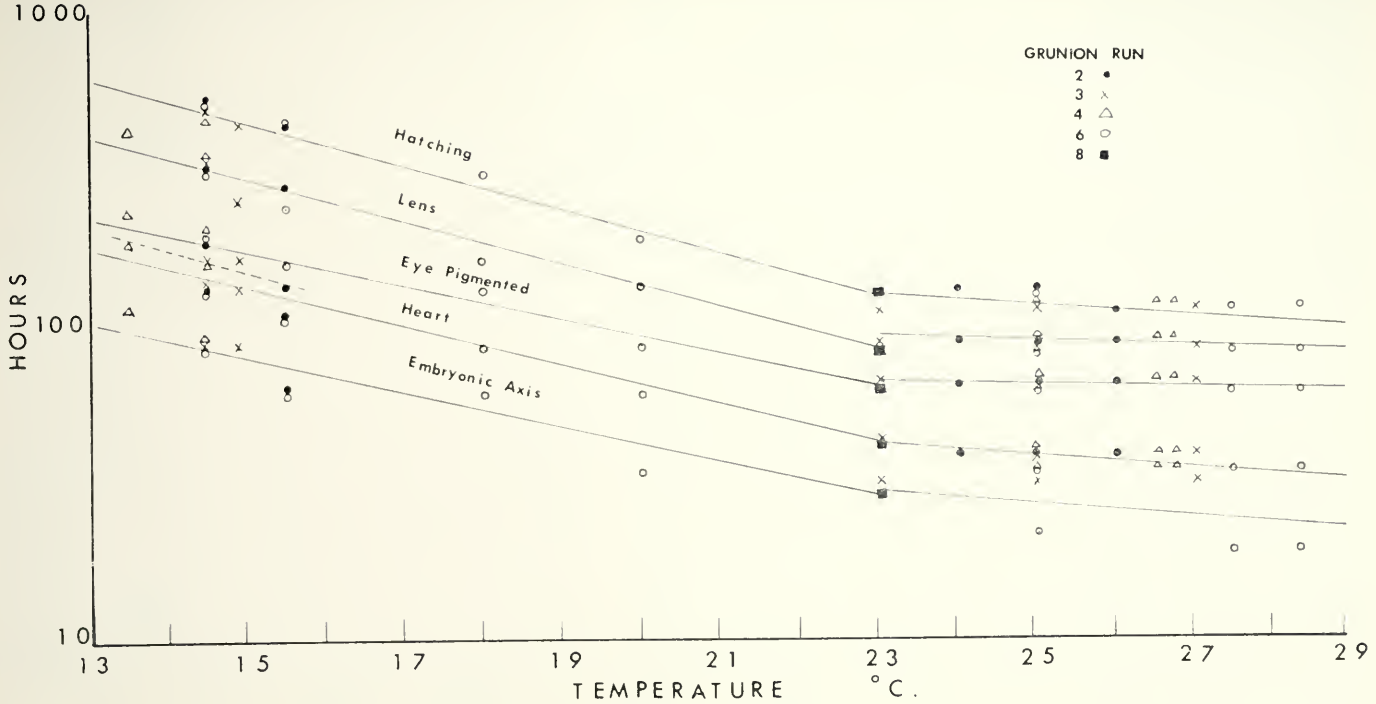

FIGURE 2. Incubation time versus temperature. Various temperatures are plotted against log time required, during different spawning runs, for the characteristics examined to first appear or be noticed. All of the slopes are equal ($b = -0.0613$, $p < 0.1$) below 23 C. Above 23 C, the slopes also are equal, but they can not be distinguished from zero ($p < 0.4$).

The average temperature coefficient in 14.0–23.0 C range was —0.0613, while that from 23.0–28.5 C could not statistically be distinguished from zero ($t\ 60df = 0.8340$, $p < 0.4$). These coefficients show that although the time required for development decreases with increasing temperature there appears to be a minimum amount of time required for an event to occur or a structure to form irrespective of temperature. Accordingly, temperatures warmer than 23.0 C did not appreciably decrease the time required for any of the examined characteristics to first appear or be noticed. The Q_{10} values for development were all approximately equal to 5 (Table 2); these were not calculated above the range 14.0–22.0 C due to the leveling off of the developmental temperature coefficient (Figure 2).

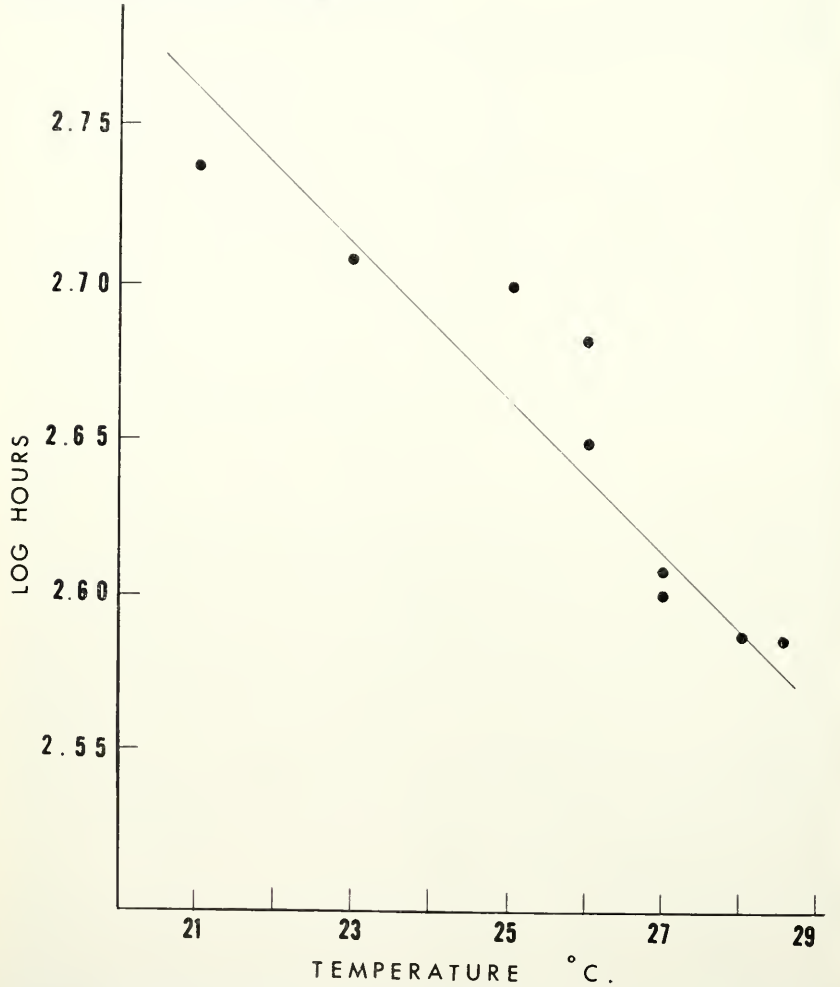

FIGURE 3. The effect of temperature upon the maintenance metabolic rate is estimated by plotting temperature against log hours from the time 50% of the eggs could first hatch, upon agitation, to when at least 50% could still hatch, after remaining in the sand for various periods, when agitated in sea water. Log hours = 3.2240 — 0.0221 Temperature C.

TABLE 2—**The Q_{10} Values for Development**

Incubation temp.	C 14	16	18	20	22
Time in hours (H) until hatching	536	387	280	202	146
Rate $\frac{1}{H}$	0.00186	0.00258	0.00357	0.00495	0.00684
Q_{10}		4.94	4.92	4.93	4.91

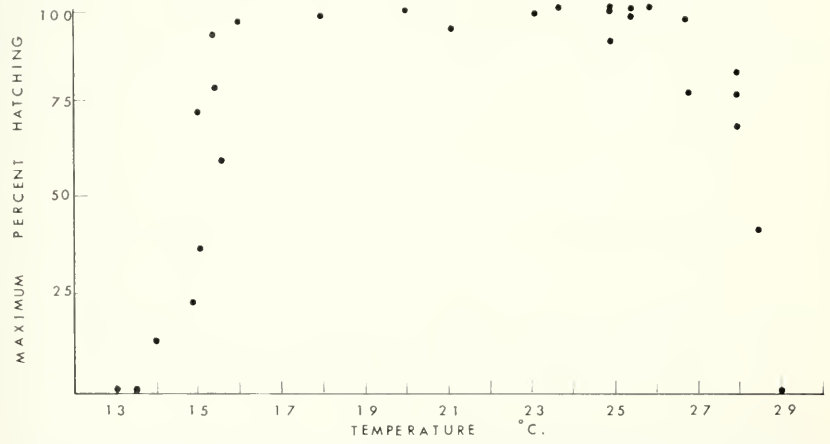

FIGURE 4. Throughout most of the viable range, the maximum percentage of hatching was close to 100; however, as the lethal limits were approached, this percentage decreased rapidly.

The temperature coefficient for maintenance was calculated above 21 C and was —0.0221 (Figure 3). This shows that at warmer temperatures the larvae could not maintain themselves as long as under cooler conditions. The maximum hatching percentage was close to 100 from 16.0–27.0 C, but on either side of this range it dropped off rapidly (Figure 4). This should be kept in mind when considering the events occurring near the end points; due to this phenomena the appearance of any of the developmental characters in this range was based on observation of fewer individuals. The length of the grunion at hatching did not appear to vary with the amount of time and temperature (degree-hours) encountered during incubation (Figure 5). This suggests that little or no growth occurs in the period after the larvae are ready to hatch and while they are waiting for a tide high enough to reach and liberate them. In conjunction with this, no other gross morphological differences were observed between larvae from eggs that spent long or short durations in the sand after developing to a point of being ready to hatch. For these reasons, we call this period, the maintenance period. The temperature at which the eggs were incubated had no effect upon the post-hatching growth rate at 18 C during the first 45 days (Figure 6).

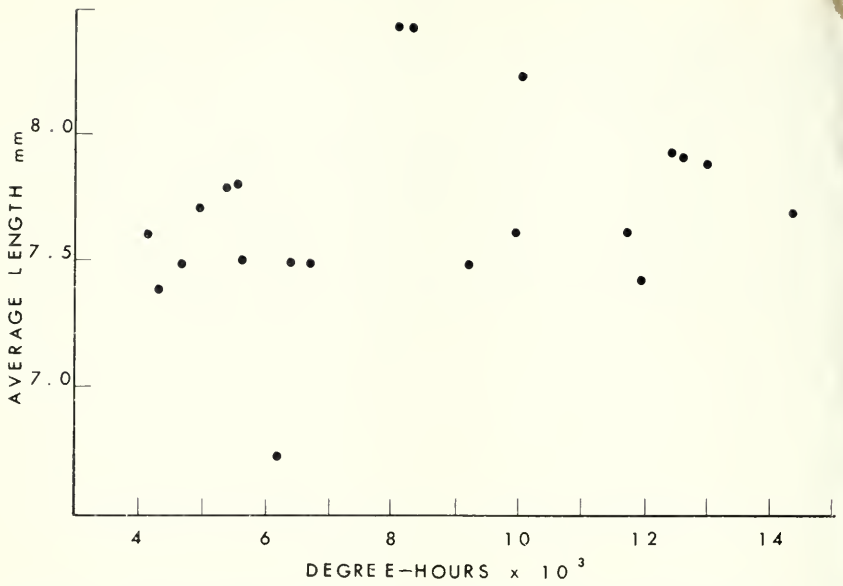

FIGURE 5. The average length of larvae at hatching was not regularly influenced by the degree-hours spent in the incubation chambers.

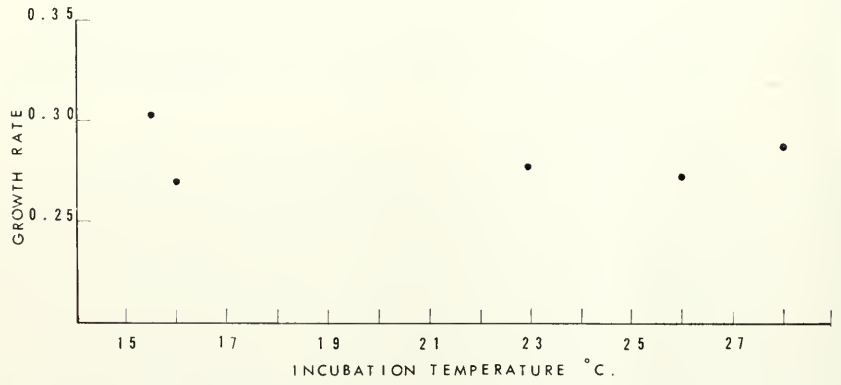

FIGURE 6. The temperature during incubation did not regularly affect the grunion's growth rate at 18 C during the first 45 days after hatching.

DISCUSSION

The yolk in the egg can be considered as consisting of two portions: that which is required for development to the point of potential hatching, and that which is for maintaining the larvae after it has completed development to this point. The latter portion is used by the larvae while it is in the egg and waiting to be freed from the sand, as well as supplying it with nutrients for growth and energy while it searches for food in the ocean.

The period after hatching and before the larvae capture food in sufficient quantities to maintain themselves is a critical period in the

fe of fishes when mass mortalities are likely to occur (Hjort, 1926). urther studies (Shelbourne, 1957; Rosenthal and Hempel, 1968) have shown yolk-sac larvae to be relatively inefficient searchers and hunters (prey capture) as compared to older larvae. Considering this, it would seem reasonable that larvae with larger yolk reserves would have a better chance of survival than those with smaller reserves. Furthermore, at any given temperature, a grunion which spends less time maintaining itself in the sand will have more yolk left when it enters the water. With a developmental temperature coefficient of zero (or close to it) at temperatures above 23 C, the amount of sand maintenance time for the grunion is decreased from what it would have been had the developmental temperature coefficient displayed below 23 C been maintained (Figure 7). The maintenance temperature coefficient

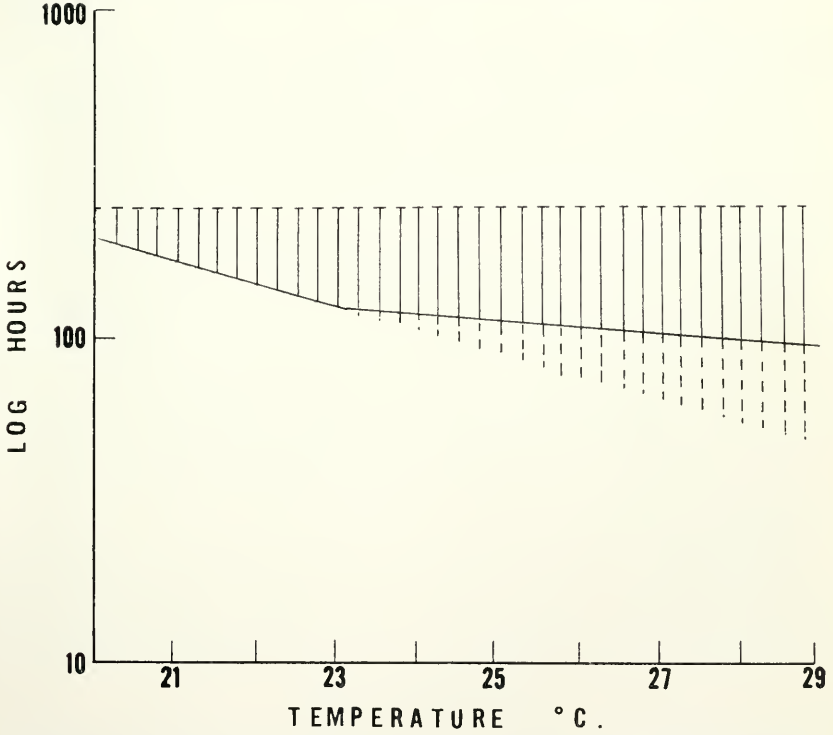

FIGURE 7. The maintenance advantage of the decrease in the developmental temperature coefficient at temperatures above 23 C. The solid lines represent the hours required for maintenance with the decrease in the development rate above 23 C. The broken vertical lines indicate the additional hours that would have been required for maintenance had there been no decrease in rate. The broken horizontal line shows the approximate time required for the eggs to be freed from the sand by wave action.

(Figure 3) shows that the decrease in the effect of temperature on development—above 23 C—would have been of greatest advantage to those fish incubated at the warmest temperatures within their viable limits. The lack of influence of the physiological age (degree-hours)

at hatching upon the hatching length is consistent with the statement of Blaxter and Hempel (1963) for herring from different areas. ". . . there is a very wide scatter of points and no consistent tendency for body size at hatching to be greater at either higher or lower temperatures."

The observed temperature tolerance range with respect to hatching (14.0–28.5 C) was broader than Hubbs (1965) reported (14.8–26.8 C). At least part of this difference might be explained by the fact that the eggs Hubbs used were placed in the temperature gradient block (used for incubation) within 15 min after they were collected. In our study, approximately 1 hr elapsed before placing them in the appropriate incubation chambers. The eggs probably had enough time during this period to at least partially acclimate to the warmer incubation temperatures. This effect would have been accentuated even further due to the time required for the gravel, after the eggs were mixed into it, to warm up or cool down to the incubation water temperature. Kelley (1968) showed that the viable temperature range for largemouth bass, *Micropterus salmoides*, eggs was extended if the eggs were allowed to acclimate slowly to warmer or cooler temperatures. Another difference in incubation technique between this work and that of Hubbs was that we incubated many eggs together in fine gravel with aerated sea water dripping over them, while Hubbs incubated single eggs in test tubes of sea water. Although the temperature coefficients for hatching were the same for both studies ($t(16df) = -0.5769$, $p < 0.6$ in the temperature range 14.0–23.0C and $t(14df = -0.2591$, $p < 0.8$ in the temperature range above 23.0C, the time required for hatching was different. (The temperature coefficient from the work done by Hubbs was computed for this study by reading points off of his published graph.) The eggs in our study hatched about 120 hr sooner—throughout the temperature range 14.0–28.5C—than those incubated by Hubbs. This difference might be explained on the basis of the variations in the experimental technique described above or possibly due to the eggs in the test tubes being under some sort of physiological stress.

As the lethal limits were approached, the development was altered before death set in. At 13.5C, near the lower temperature limit, the eggs developed through lens formation but did not hatch. At warm temperatures (28.0C), about one-third of the eggs developed normally, but others had stunted bodies, and the eyes were sometimes fused. The percentage of hatching decreased sharply at these temperatures (Figure 4).

Giese (1962) stated that there are four different kinds of Q_{10} values related to different mechanisms of action: ". . . those which are about two, those which are considerably higher than two, those which are considerably less than two, and those which are about one." The Q_{10} values for development obtained in this work (Table 2) would probably be classified as falling into the first category. Blaxter (1956) found for hatching and yolk-sac absorption of herring that Q_{10} values of about two were obtained only throughout the temperature range the fish would encounter normally. The values decreased above these temperatures; while below them, values increased. In this study, the values of Q_{10} did not vary throughout the range of 14–22C which suggests bio-

chemical reactions occurring in grunion are more stable over a wider temperature range than those occurring in the herring. This is understandable considering that grunion eggs develop in beach sand, while those of the herring develop in open water.

No attempt was made to measure the bacterial count of incubation chambers at various temperatures. However, the effect of them on the eggs—with respect to hatching—throughout most of the temperature range was probably minimal. This statement is based on the fact that the percentage of eggs hatching was about 100 throughout the temperature range, excluding the end points near the lethal limits. Although fungus developed on some eggs that were in the incubation chamber for over 2 weeks, it was not possible to determine whether the buildup of fungus caused the eggs to weaken and die or whether fungus only grew on those eggs already weakened by some other factor.

SUMMARY

1. Grunion eggs were collected throughout their spawning season and incubated at different temperatures.
2. The viable limit for hatching was 14.0–28.5C.
3. During incubation, the development of these characteristics was followed: embryonic axis formation, heart beating, eye pigmentation, lens formation, and hatching. All of these displayed the same developmental temperature coefficients, but two distinct coefficients were found within the viable range (—0.0613 from 14.0–23.0C, and —0.0113 from 23.0—28.5C). The lower coefficient at higher temperatures could serve to conserve yolk for the larvae for use in the sea after hatching.
4. A temperature coefficient of —0.0221 was determined for the maintenance of the grunion in the sand after it completed development to the point of being ready to hatch and while awaiting a tide high enough to reach and free it.
5. The maximum percentage of hatching was close to 100 in the range 16.0–27.0C but dropped off rapidly on either side.
6. The average hatching length of the grunion was not influenced by the degree-hours incubated.
7. The post-hatching growth rate of the larvae, at 18C, was not influenced by the incubation temperature within the viable range.

ACKNOWLEDGMENTS

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A REVIEW OF POSSIBLE CAUSES OF MORTALITY OF OYSTER LARVAE OF THE GENUS *CRASSOSTREA* IN TOMALES BAY, CALIFORNIA[1]

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Oysters of the genus *Crassostrea* do not produce successive generations in Tomales Bay, California, because of the failure of the larvae to survive and set. Excessive turbidities, lack of proper food, and blooms of dinoflagellates are probably the major causes of oyster larvae mortality, although there are other contributing factors.

INTRODUCTION

Recent work on the reproductive cycles of the giant Pacific oyster, *Crassostrea gigas* (Thunberg, 1793), and the eastern oyster, *Crassostrea virginica* (Gmelin, 1791), showed that both introduced species spawn in Tomales Bay, California. Failure of these oysters to produce successive generations in the bay was attributed to the inability of the larvae to survive and set (Berg, 1969). The great fecundity of the oysters and the occurrence of mass spawning ensures a large number of larvae being produced even if only a small percent of the ova are fertilized. The presence of a few *Crassostrea* spp. larvae in the waters over Tomales Bay Oyster Company beds demonstrated that at least some of the zygotes were viable. Therefore, conditions not inherent in the oysters themselves probably were responsible for larval loss.

Apparently, many environmental factors are involved, both singly and in combination, in the mortality of oyster larvae. This attempt to designate the factors probably responsible for the larval loss is based on the observations of both biological and physical factors prevailing in Tomales Bay. Not all of these factors were examined at the time the larvae were present (from the end of June through September, 1967), but the hydrographic character of the area comprising Tomales Bay Oyster Company was well monitored during that period. Temperature, salinity, hydrogen-ion concentration, and turbidity measurements were recorded for both surface and bottom water at biweekly intervals and more often at times. All samples and temperature readings were taken at low or mid-tides. This paper describes parameters which apparently caused high larval mortality in Tomales Bay.

TEMPERATURE

Water temperature fluctuations in Tomales Bay were minimal while larvae were present, with temperatures ranging from 19.0 to 21.4 C. The fact that early morning temperatures were 19.0 C or higher, suggests the water seldom got much colder than 20.0 C during July and

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August (Berg, 1969). If the water temperature had dropped, it would have been quickly warmed by the sun.

The effect of temperature upon bivalve larvae has been reported by Seno, Hori, and Kusakabe (1926); Loosanoff and Davis (1963a); and by Davis and Calabrese (1964). The temperatures recorded at Tomales Bay Oyster Company during the study period were well within the range of 17.5 to 35.0 C which is considered the approximate limits for normal development to the straight-hinge stage. Since Loosanoff and Davis (1963b) show that short periods of very low temperatures will not kill larvae, it is unlikely that temperature conditions were responsible for the scarcity of oyster larvae in Tomales Bay. However, low temperature may affect the oyster larvae detrimentally by prolonging their pelagic stage, thus offering a greater chance for mortality, predation, and dispersal. In their natural environment in the waters of Long Island Sound, the larvae may take as long as 40 days to reach the setting stage at 20.0 C and at a salinity of 27‰ (Davis and Calabrese, 1964). In the colder waters of Tomales Bay, it is probable that larval development would take much longer, which in turn decreases the larvae's chances of survival.

SALINITY

Davis and Calabrese (1964) also show the effects of various combinations of temperatures and salinities on bivalve larvae. Unfavorable salinities reduce the number of larvae reaching metamorphosis and limit the range of temperature tolerances. Although Davis and Calabrese dealt extensively with the range of salinities oysters might encounter in Long Island Sound, little work has been reported on larval tolerances to salinities as high as 35‰ which are encountered during the summer at Tomales Bay Oyster Company. Loosanoff and Davis (1963b) observed that some larvae from Long Island Sound oysters may develop normally at 35‰, and Amemiya (1926) and Clark (1935) extended the salinity limits for normal development to 39‰. In a later paper, Amemiya (1928) states that between 31‰ and 34‰ only a small proportion of oyster larvae attain normal development. Imai et al. (1950) report that giant Pacific oyster larvae successfully set in Japanese waters with salinities of 30‰ to 32‰. W. W. Budge (Pacific Mariculture, Inc., pers. comm.) has noted that the larvae of eastern and giant Pacific oysters raised in California waters grow well at a salinity near 35‰. This supports Davis's (1958) statement that the salinity range for the development of straight-hinge larvae is, in part, governed by the salinity in which the parent oysters develop gonads. Salinity measurements for Tomales Bay ranged from 27.8 to 34.8‰. Therefore, I conclude that the salinity of Tomales Bay was probably not detrimental to the larvae of either species.

HYDROGEN-ION CONCENTRATION

The effect of hydrogen-ion concentration upon oyster gametes and larvae has been studied by Calabrese and Davis (1966, 1969). They found that at a salinity of 27‰ the pH may range from 6.75 to 8.75 and still result in normal larval development, survival, and growth. During the study period, the pH of the water at Tomales Bay Oyster

Company was remarkably constant, ranging between 7.64 and 7.96. This is the approximate midrange of values reported for normal development.

Calabrese and Davis (1966) also reported that high concentrations of suspended silt can lower the pH below the limit for development. Excessive turbidities observed at Tomales Bay Oyster Company may have reduced the pH temporarily and thus caused mass larval mortality, but while the water was usually very turbid at the time of sampling, low pH readings were never recorded. Thus it is not likely that the hydrogen-ion concentration was a factor in larval mortalities.

TURBIDITY

Excessive turbidities may affect oyster larvae. Turbidity caused by suspended silt, detritus, or unicellular organisms harms oysters by clogging their gills (Loosanoff and Engle, 1947; Davis, 1953; Loosanoff, 1954; 1958; 1962; Ukeles and Sweeny, 1969). At high temperatures (20.0 C), turbidity may cause rapid suffocation and starvation even in adult bivalves (Loosanoff, 1962). In solutions with as little as 0.5 g/liter of silt, only 31% of the oyster eggs developed to the straight-hinge larval stage, and growth of the surviving larvae was seriously affected. Practically no eggs survived at greater concentrations (Davis and Hidu, 1969). Extreme turbidities at Tomales Bay Oyster Company during the summer may be one of the major causes of larval mortalities.

These excessive turbidities had the greatest deleterious effect upon oyster propagation by covering all possible places for settlement with a layer of mud. Clean shells, on which spat normally set, were completely covered by silt within 2 weeks. The only oyster spat found had set on the underside of the upper valve of a slightly gaping oyster. Because of the timely gaping and the narrow opening it formed, the spat found a clean area on which to settle. At times, mud on the oyster shells was as thick as 0.5 cm and was often infested with the amphipod *Corophium* sp. Even though clean shells were suspended from the oyster racks every 2 weeks, few spat were found, nor did other animals settle on the shells. A few barnacles and hydroids were found on the shells in early and late summer, but during the period of maximum oyster spawning even these forms did not settle on the mud covered shells. Without a place to set, the pelagic period of the oyster larvae was probably prolonged until the larvae died or were carried from the bay by tidal currents.

ORGANIC CHARACTER

Unfavorable changes in larval growth have been related to organic constituents of the water liberated from bottom sediments (Davis, 1953; Ito and Imai, 1954; Loosanoff, 1958). Oysters are placed on a soft mud bottom in Tomales Bay. Because of the shallowness of the water, large waves and wakes of motorboats cause extensive bottom disturbances. With the great number of boats in the water during the summer months, large amounts of organic matter are released from bottom sediments. Wilson (1951) and Millar and Scott (1968) noticed differences in larval development which they attributed to a biological difference in sea waters. Loosanoff, Engle, and Nomejko (1955) dis-

cussed a "water factor" consisting of certain dissolved substances needed for development of bivalve larvae. All organic chemical substances that may affect organisms via the external medium have been termed "ectocrines" by Lucas (1947), and will be mentioned again in the section on metabolites. The bottom disturbances and the excessive turbidities in Tomales Bay may have contributed a "water factor" or "ectocrine" which caused oyster larval mortality. No attempts were made to test this hypothesis.

FOOD

In addition to the physical and chemical aspects of the environment, biological aspects play a most decisive role in oyster development. Having the proper food available for larval consumption is one of the most important factors in larval development. In fact, Loosanoff (1950) attributes the variations in Long Island Sound oyster set to the absence of proper food. Loosanoff and Davis (1963b) state that the larval pelagic period may be extended or larvae may never metamorphose if specific food organisms are lacking or are uncommon in the environment. It has been demonstrated that larvae of *Crassostrea* spp. are able to utilize only a few of the many organisms available (Davis, 1953; Loosanoff, 1954; Loosanoff, Engle, and Nomejko, 1955). The thickness of the algal cell walls, the toxicity of algal metabolic products, and water temperature are all important factors in determining the algal cells' value as larval food (Loosanoff, 1965). I did not use a phytoplankton net with mesh fine enough to retain naked flagellates which are the best food for larval oysters (Loosanoff and Davis, 1963b), therefore, I can not evaluate local forms. Since food requirements are very specific, larvae of introduced *Crassostrea* spp. may not have been able to find sufficient nutrients in Tomales Bay waters and hence starved to death.

METABOLITES

External metabolites of food organisms and other unicellular organisms present in the water may be toxic to bivalve larvae. Blooms of dinoflagellates produce metabolic excreta which cause abnormal larval development, characterized by the scarcity or absence of early straight-hinge larvae (Davis and Chanley, 1956; Loosanoff, 1958). Excessive concentrations of metabolites may affect larvae directly or may kill the nannoplankton, starving the larvae or making them more susceptible to disease. Furthermore, the large numbers of organisms producing metabolites also may harm larvae by using up chemicals in the sea water that are essential to larval development (Loosanoff and Davis, 1963b). A large bloom of the dinoflagellate *Gymnodinium* sp. was observed by members of the Pacific Marine Station staff in the summer of 1967 during the period of greatest spawning of both eastern and giant Pacific oysters. In addition to *Gymnodinium*, large concentrations of a unicellular ciliate of the family Tintinnidae were taken in plankton samples throughout the summer. Both of these organisms may have produced toxic metabolites. Only straight-hinge larvae were found in plankton samples, and the disappearance of older oyster larvae may well be due to a cumulative effect of external metabolites in the water and the depletion of nutrients.

PREDATION

The Tintinnidae may have had another effect upon oyster larvae. Loosanoff (1959) reports that ciliates of the families Condylostomidae and Folliculinidae may ingest bivalve larvae. Although no larvae were observed in the digestive tracts of any preserved specimens of Tintinnidae, the latter were present in sufficient numbers to cause severe depletion of larvae if the ciliates did ingest them.

Large numbers of the scyphomedusae *Aurelia aurita* and *Chrysaora melanaster* also were present during the oyster spawning season. Although Loosanoff (1966) could find no direct relation between numbers of ctenophores and the oyster set in Long Island Sound, predation by ctenophores and coelenterates upon oyster larvae is well known (Thorson, 1946; Korringa, 1952).

A great number of herring and smelt were present in the bay during the summer. Thorson (1946), in his discussion of predation on pelagic larvae, considers fishes the principal enemies of larvae, but suggests that filter feeders such as barnacles, mussels, and the oysters themselves also are important. It appears that the animals that were in the greatest abundance during the summer were those that may have shown the greatest predation on bivalve larvae. Few bivalve larvae of any species were present during the summer and predation is suggested as one of the major reasons for lack of oyster spat in Tomales Bay.

DISEASE

The effect of bacterial and fungal diseases on oyster larvae has been described. Davis et al. (1954) and Loosanoff (1965) state that most larvae in culture chambers stopped growing and died soon after they were infected with the fungus *Sirolpidium zoophthorum*. Lethal effects of live bacteria and their toxins have been similarly discussed by Davis (1953), Walne (1958), Guillard (1959), and Tubiash, Chanley, and Leifson (1965). An infection of epidemic proportions among pelagic larvae in constantly mixing waters over Tomales Bay oyster beds is not likely.

CONCLUSIONS

The inability of oysters of the genus *Crassostrea* to produce successive generations in Tomales Bay should be attributed to failure of larval survival and set, since the adults do spawn. No single factor can be held accountable for the absence of oyster spat. Many adverse conditions, such as low temperature, absence of proper food, and lack of suitable surfaces on which to set, while perhaps not lethal themselves, prolong the pelagic period and thus increase chance of larval loss due to predation, mortality, or dispersal by tidal currents. Apparently dispersal is a relatively unimportant factor in Tomales Bay which has a low flushing rate, and spat were not found in other areas of the bay.

Lack of proper food and nutrients probably is a very important factor since the extreme irregularity of oyster set in Long Island Sound has been attributed to absence of proper food and not to physical environmental characters or predation (Loosanoff, 1950). In Tomales Bay, extreme turbidity is responsible for larval loss because all possible places where oyster larvae may settle are soon covered with a layer of

mud. Blooms of dinoflagellates are the third major cause of larval mortality. Other causes are not likely as important as these three, but do contribute to generally unfavorable conditions for oyster larvae in Tomales Bay.

Even in their native environments, oysters, such as *Ostrea edulis* which have a shorter pelagic period than the oviparous *Crassostrea* species, have as few as 5% of the larvae produced at 20.0 C, reaching metamorphosis. Only 1% of these mature larvae are able to find substrates on which to settle (Korringa, 1952). Therefore, it is not surprising that so few oyster larvae set when so many factors are against them in the foreign environment of Tomales Bay.

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ANGUILLA RECORDED FROM CALIFORNIA[1]

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Two specimens of the Family Anguillidae (true eels) have been taken alive in the Sacramento-San Joaquin Delta of California. The first was taken in 1964 by a local fisherman and was identified by Dr. Carl Hubbs of the Scripps Institution of Oceanography as *Anguilla rostrata* (Le Sueur). The second was captured at a State-operated fish salvage facility on January 24, 1969 and was subsequently identified by Mr. W. I. Follett, Curator of Fishes for the California Academy of Sciences, as *Anguilla anguilla* (Linnaeus).

SPECIMENS TAKEN

Anguilla anguilla (Linnaeus)

On January 24, 1969, a European eel, *Anguilla anguilla* (Linnaeus), was collected during routine fish salvage operations at the State's Delta Fish Protective Facility near Byron, Contra Costa County, California. This Facility is a louver fish screen located on an extension of Italian Slough, a natural deadend tidal reach. This slough connects directly with Old River and thence with the San Joaquin River, which flows westward to the Pacific Ocean. The capture site is approximately 65 airline miles east of San Francisco.

The fish, an adult female that initially measured 925 mm in total length, was captured at about 1900 hours at an ambient water temperature of approximately 11 C. It was brought to the attention of the author by John Massie, an employee working at the Facility.

FIGURE 1. *Anguilla anguilla* (Linnaeus) captured January 24, 1969.

The specimen under consideration was submitted to Mr. W. I. Follett, Curator of Fishes for the California Academy of Sciences, San Francisco, who identified it as *Anguilla anguilla* (Linnaeus, 1758). In sup-

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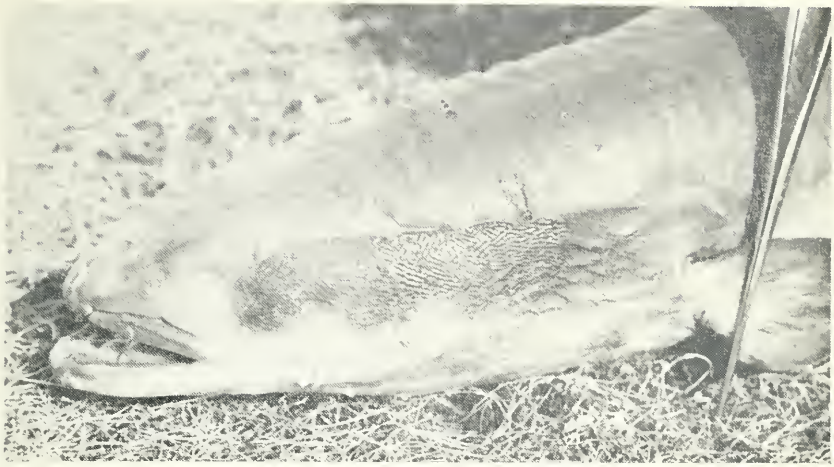

FIGURE 2. Close up of the head of *Anguilla anguilla*.

port of the identification the following is quoted from a letter from Mr. Follett to the author (July 4, 1969):

"In preservative, the specimen now measures 916 mm total length; this large size indicates that it is a female (Carl L. Hubbs, personal communication).

"I have concluded that this specimen represents the European eel, *Anguilla anguilla* (Linnaeus, 1758).

"A radiograph shows the total number of vertebrae to be 114. According to Ege (1939, p. 132), this count eliminates *Anguilla rostrata*, which has 103 to 111 vertebrae, but not *Anguilla anguilla* (110–119) nor *Anguilla japonica* (112–119) nor any of the following species of *Anguilla* (see Ege, on the pages indicated parenthetically, after the vertebral counts): *megastoma* (110–114; p. 26), *nebulosa labiata* (107–115; p. 72), *dieffenbachi* (109–116; p. 133), *australis australis* (111–115; p. 188), *australis schmidti* (109–115; p. 189).

"The same radiograph shows (though not so clearly) the number of precaudal ('prehaemal' of Ege, 1939) vertebrae to be 46. According to Ege (p. 130), this count is well within the range of *Anguilla anguilla* (44–47), but is beyond that of *Anguilla japonica* (42–45). (The count of 46 precaudal vertebrae eliminates *Anguilla megastoma* and *Anguilla nebulosa labiata;* see Ege, pp. 26, 70.)

"Other characters of the present specimen that agree with those of *Anguilla anguilla*, but not with those of *Anguilla japonica*, are the following:

1. Preanal length without head, in hundredths of total length: 30.2 (this length is modal for *A. anguilla;* see Ege, p. 234).

2. Distance between verticals through anus and origin of dorsal fin, in hundredths of total length: 12.2 (see Ege, p. 100). (This distance eliminates *Anguilla australis australis* and *Anguilla australis schmidti;* see Ege, p. 163).

3. Distance from perpendicular through eye-center on margin of upper jaw to angle of gape, in hundredths of length of gape: 12.5 (see Ege, pp. 110–111). (This distance eliminates *Anguilla dieffenbachi;* see Ege, p. 111).

"The foregoing are my reasons for concluding that your specimen represents the European eel, *Anguilla anguilla* (Linnaeus, 1758). We have so catalogued it, as California Academy of Sciences No. 27136.

"The paper that I have cited as Ege, 1939, is the following: Ege, Vilh. 1939. A revision of the genus *Anguilla* Shaw. A systematic, phylogenetic and geographical study. Dana-Report No. 16:1–256."

Anguilla rostrata (Le Sueur)

The week of June 1–5, 1964, Mr. Dennis Ivy, a Stockton resident, caught an eel in the vicinity of Honker Cut and Disappointment

Slough near King Island Resort, 15 miles northwest of Stockton while angling. This specimen was caught at about 1700 hours, on a hook baited with "fresh water clam" while Mr. Ivy was fishing for catfish. It was reported to be approximately 30 inches in length with "white belly, olive drab sides and back".

The resort owner, Mr. Lloyd Chelseth, called the strange catch to the attention of the local warden (Harold Hale) who contacted Mr. Ivy, only to find the fish had been skinned out and fed to his dog (letter from Harold Hale to Robert D. Montgomery, June 19, 1964). Fortunately, he had retained the skin. Through Fish and Game Department personnel the skin and a photograph of the fish eventually reached Dr. Carl Hubbs. The skin of this specimen has been retained at the Institution and is catalogued as SIO 64–219.

Dr. Hubbs identified the specimen at that time as *Anguilla rostrata* (Le Sueur) (letter to David Ganssle, June 16, 1964). Upon learning the specimen taken in January 1969 was *Anguilla anguilla*, Dr. Hubbs reexamined the photograph and skin of the 1964 specimen using the procedure outlined by Ege (op. cit.) for identification purposes. The following is quoted from Dr. Hubbs' letter to the author dated April 6, 1970.

> "The nearest approximations I can make of critical parts of the body, using Ege's methods of measuring, as specified on p. 7 and fig. 1 in the paper cited by Follett:
>
> "Length to vertical below dorsal origin, minus head length measures 16 or possibly 17 mm on the photograph, yielding the percentage values of 22 or possibly 24. Comparison with Ege's table 104 on p. 103 seems to eliminate *japonica* and almost certainly *anguilla*, but agrees with *rostrata*. Follett's measurements yield a value of 18, by subtracting the percentage value for the interval between vertical through anus and origin of dorsal fin (12.2) from that for the preanal length without head (30.2); this value fits Ege's for either *anguilla* or *japonica*, but not for *rostrata*.
>
> "Length to vertical above anus, minus head, seems to be 21.5 mm., yielding the percentage value of 30, apparently eliminating *japonica*, as I stated before, but agreeing with either *rostrata* or *anguilla* (by comparison with Ege's table 97 on p. 97).
>
> "Corresponding measurements including head seem to yield the same conclusions.
>
> "The probable proportionate value of 10 for the interval between verticals through anus and origin of dorsal fin seems to fit either *japonica* or *rostrata* better than *anguilla* (as tallied by Ege on table 100, p. 100). Follett's value of 12.2 fits only *anguilla*.
>
> "Hence, I conclude that both *A. rostrata* and *A. anguilla* have somehow made their way into California in recent years."

DISCUSSION

It seems most probable that both specimens represent isolated cases of accidental origin, rather than representatives of a species in the process of becoming established in the area. Pursuing the former, the most probable sources are: (1) the aquarium trade, (2) the epicurean trade, (3) straying, (4) ship ballast.

Limited contact with personnel knowledgeable regarding the first two sources indicates that both are extremely unlikely. The larger public aquariums have denied importing European eels. Though sought fresh for food purposes, eels are rarely imported alive. The possibility that either eel reached the Delta by straying seems extremely remote but, if true, probably represents some kind of record for such an event.

I believe the most logical explanation for the occurrence of both eels is that they were transported from abroad in the ballast of commercial ships. The cities of Sacramento and Stockton have both been opened to ships of foreign commerce within the past two decades or so. It is entirely plausible that ships taking on ballast in foreign ports or at sea could have entrapped the eels and transported them to this area and then expelled them with the ballast. The Japanese goby, *Acanthogobius flavimanus* (Temminch and Schlegel), now firmly established in the San Francisco Bay and estaurine system, is thought to have been introduced in a similar manner (Brittan, Albrecht and Hopkirk, 1963).

The only prior records of eels in California date back to introductions of the American eel, *Anguilla rostrata* (Le Sueur) which were made in 1874, 1879 and 1882 (Shebley 1917 and Evermann, Warren and Clark, 1931). Of these introductions, Shapovalov, Dill and Cordone (1959) state only that, "There are no authentic records of survival". No other introduction of eels in California has been documented or reported.

The ecological consequences of eels in the San Francisco Bay-Delta estuary are such that their occurrence should be documented carefully.

ACKNOWLEDGMENTS

John Massie, formerly a Fish and Wildlife Assistant at the Delta Fish Protective Facility, deserves special commendation for his alertness in recognizing and saving the eel taken at the fish facility. I also wish to acknowledge the considerable efforts of W. I. Follett, Curator of Fishes of the California Academy of Sciences, who identified the specimen of *Anguilla anguilla* and Dr. Carl Hubbs, who identified *Anguilla rostrata*.

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BOOK REVIEWS

Trout Streams: Conditions That Determine Their Productivity and Suggestions for Stream and Lake Management

By Paul R. Needham; Annotated by Carl F. Bond; Holden-Day, Inc., San Francisco, 1969; x + 241 p., illustrated. $8.50.

The first edition of *Trout Streams*, published in 1938, was written in response to a long felt need for information about the food, habitat, and management of trout in streams in a single volume.

Much additional knowledge about trout has been gathered and published in the following years, but not summarized under one cover. The need for an updating of *Trout Streams* was clearly evident.

The title page states that the book has been "revised", while the jacket says "annotated". The latter is the more descriptive term. Dr. Bond has changed only a few words in the text, but has added a good foreword and a number of footnotes and literature citations to reflect new findings and developments. Unfortunately, the footnotes do not show whether they are Needham's or Bond's. A comparison of the two editions reveals that in the first 100 pages 30 of the footnotes are by Bond, while 21 are Needham's.

Dr. Bond has done a thoughtful and workmanlike job with his footnotes, but for meaningful updating some passages remain in need of revision.

The section on "Golden Trout", pages 42–43 is an example. The impression that golden trout are found only "at elevations around 10,000 feet", is perpetuated and also stated in many other publications. Actually, the native range extended down to around 6,400 feet. The California bag and size limits listed are obsolete. Golden trout are not now "limited to high mountain areas in Central California", but have been transplanted to many other waters in California and to several other states. It is true that within their native range golden trout seldom exceeded 10 inches, but in lakes to which they have been transplanted they reach a much larger size. The world's record golden trout, taken in Wyoming, weighed 11 pounds. A 9½-pound golden was taken in California. Thus, the unitiated reader will be misinformed in his knowledge of golden trout.—*Leo Shapovalov.*

Olfaction in Fishes

By Herman Kleerekoper; Indiana University Press, Bloomington, 1969; VIII + 222 p., illustrated. $12.50.

In this book, Mr. Kleerekoper reviews the literature of the past 100 years that deals with olfaction in fishes and summarizes the most significant contributions. He divides this information into two categories and devotes a chapter to each. The first chapter deals with the development, structure and function of olfactory organs in fishes, while the second discusses the role of olfaction in fish behavior.

The first chapter, on which the author places his emphasis, is, by the nature of its content and the manner in which it is written, likely to be of interest only to a few specialists or those particularly interested in olfaction. The second chapter, however, contains much information of concern to fishery biologists. It starts with a summarization of the old controversy as to whether or not aquatic animals actually have a sense of smell. This is followed by discussions on the followings topics: "Role of Olfaction in the Procurement of Food", "Olfaction and Social Behavior", "Olfaction and Defense Mechanisms", "Role of Olfaction in Parental Behavior", "Olfaction and Homing Orientation", and "Mechanisms of Orientation Through Olfaction",

An appendix entitled "Methods Used for the Observation and Recording of Some Locomotor Patterns in Fishes" follows the text and there is a 704 reference bibliography that reaches back to 1807.

This is a comprehensive review on the fields of olfaction and its influence in the life of fishes. It is clearly a must for anyone seriously interested in these subjects.—*Franklin G. Hoover*

Fisheries Year Book and Directory 1968–69

Edited by Harry F. Tysser; British-Continental Trade Press Ltd., London, 1968; 444 p., illustrated. £2.

The 1968–69 edition of *Fisheries Year Book and Directory* provides an international guide to firms engaged in the fishery industry and fishing trades. Information on some 90 varieties of market fish and over 6,000 firms are presented in the edition.

A world fisheries survey of 33 nations provides the background for the editorial and reference material that follows.

The editorial chapters present status reports on the cultivation of fish and shellfish and other investigations and research being conducted in the United Kingdom.

Reference chapters cover a dictionary of fish names in 8 languages, a fish supply calendar, listings of organizations and trade associations, trade journals of interest to industry, reports on marketing, quick freezing, and oil and meal. A survey of new fishing vessels completed or on order and new equipment is also included.

In the directory section, listing of firms engaged in all facets of industrial support allied to the fishing industry are indexed by national origin. Of particular interest to the industry is a classified buyers guide.

The wide range of information presented in this book makes it a valuable reference to persons interested in all phases of the international fishing industry.—*J. Gary Smith*

1. *Biometry: The Principles and Practice of Statistics in Biological Research*

By Robert R. Sokal and F. James Rohlf; W. H. Freeman and Co., San Francisco, 1969; xxi + 776 p., illustrated. $15.00.

According to the authors, this book is aimed at academic biologists. It covers the subject of statistics from an elementary introduction up to advanced methods. It is designed to be used for either a formal text with a course in statistics or for self-study.

The text represents the minimum required knowledge in statistics for a Ph.D. in biological sciences. The most important topics treated are simple statistical tests (including nonparametric tests), analysis of variance through factorial analysis, analysis of frequencies, regression and correlation.

The authors have found little correlation between innate mathematical ability and capability to understand biometrical methods. Statistical theory and mathematical derivations are therefore kept to a minimum, and emphasis is placed on teaching the students about which methods apply when, and how to apply them.

Special tables labeled "boxes" illustrate computational methods step-by-step, serving later as quick summary reminders of techniques.

One chapter of the book deals with the application of digital computers to the solution of statistical problems. Several statistical programs are written in FORTRAN and included in an appendix.

Another appendix contains a key to statistical methods based on the purpose of research problems, by whether they are based on one or more samples, by whether the data are measurement variables or attributes, and other similar considerations. The key eventually leads the researcher to one of the "boxes" or other places in the book in which an appropriate method is featured.

The direct and personal style used by the authors and the wide but thorough coverage of the subject make this book a good prospect for biologists looking for a reference work on statistics.—*Timothy C. Farley.*

2. *Statistical Tables*

By F. James Rohlf and Robert R. Sokal; W. H. Freeman and Co., San Francisco, 1969; xi + 253 p., illustrated. $7.50 cloth, $2.75 paper.

The authors state that they included the statistical tables accompanying their text in a separate volume for ease of reference; rather than searching through the text or thumbing to the back of the book to find a table referenced by the text, the reader can view both items simultaneously.

An introduction section on interpolation plus 33 tables and a list of mathematical constants make up the book. Each table has clear, concise instructions on its use.—*Timothy C. Farley.*

Seashore Life of Southern California: An Introduction to the Animal Life of California Beaches South of Santa Barbara

By Sam Hinton; University of California Press; Berkeley and Los Angeles, 1969; 181 p., illustrated in color and black-and-white. $2.25 paper.

This informative and very readable booklet appears to be an expansion of Common Seashore Life of Southern California by Joel Hedgpeth and Sam Hinton (Naturgraph Company, 1961) and as such will be a welcome addition to many libraries.

Unfortunately, despite the author's efforts, there are many inaccuracies and inconsistencies in the text (e.g. the lack of required parentheses around certain authors' names, even though there is a lengthy discussion of this in the section on the Classification of Animals; the incorrect statement that the solitary coral, *Astrangia lajollaensis*, is often found on the fronds of giant kelp; the failure to mention that the tube worm, *Chaetopterus variopedatus*, is a typical inhabitant on marina floats, pilings, and the undersides of offshore rocks; the use of Bryozoa rather than Ectoprocta to conform to the use of Endoprocta in listing phyla; the failure to cite the California cone's small radula as the reason it has never been implicated in a human sting; the many molluscan names which are not in keeping with recent literature; the fact that the poisonous sea urchin, *Centrechinus maxicanus*, reported from Mission Bay, is probably *Centrostephanus coronatus*, a commonsubtidal inhabitant not mentioned in this book; etc.). These errors and omissions will not bother the casual lay reader, who will be unaware of them, nor will they seriously trouble the specialist, who will immediately recognize them. They will, however, cause trouble for the pseudo-specialist, those semi-learned and still learning marine scientists employed by the numerous consulting and aero-space firms who have only recently discovered the ocean. Such workers all to frequently use booklets such as this as a panacea to answer their every inquiry regarding the ocean.

It is hoped that this book will be used as it is presumably intended, a general introduction to seashore life, and that a more thorough treatise will be sought for answers to specific questions concerning the nearshore marine environment and its ecology.—*Charles H. Turner*

Freshwater Fishes of Alabama

By William F. Smith—Vaniz; Exp. Sta., Auburn University, Auburn, Ala., 1968; V + 211 p., illustrated.

The last checklist of fishes in Alabama was written in 1865. The purpose of *Freshwater Fishes of Alabama* is to update that list, since some 50 new species have been reported. The author hopes this latest work will also serve as a research reference for future, more comprehensive work.

Species included are freshwater and a few marine species that occasionally occur during low flow periods of saline water intrusion.

The contents include a brief history of ichthyology in Alabama; a discussion of common counts and measurements used and a glossary of key characteristics; a key to families, and when two or more species common to a family are described, a key to species is presented. An annotated checklist following the key to species provides information on the known distribution in the State. An additional reference to distribution is presented in several tables which relate the species to the 18 major river systems.

The author, in a rather "bare bones" fashion, has accomplished all of his goals, particularly in demonstrating the need for future, more comprehensive work. There was no stated or obvious logic in the sequence or composition of photographs presented at the end of the book. The photographs are in black and white and often are poor in quality. I am certain they would be of little help in identifying species. The line illustrations of critical key characteristics in the keys would be helpful, however.—*Larry K. Puckett*

Population, Resources, Environment

By Paul R. and Anne H. Ehrlich; W. H. Freeman and Co., Inc., San Francisco, California, 1970; 383 p., illustrated. $8.95.

Richard Goodwin of Connecticut College once said, "If I have any message for you it is only this, that the biologist has a higher duty than that of merely practicing his profession. He has special responsibilities because of his privileged position as an educated person, as a scientist and as a student of living organisms to play an active part in shaping human affairs; to have his hands, so to speak,

on the space-ship controls. As a man he eats, drinks, pursues happiness, votes, reproduces and influences others. He is an integral part of the social system. As a leader he must be constantly mindful of the health of the entire enterprise."

This monumental work provides the first comprehensive, detailed analysis of the health of the entire enterprise and in particular the worldwide crisis of overpopulation and the resulting demands on food, resources, and the environment. The book covers a broad range of subjects from the destruction of the whale and sardine fisheries to a very readable section on pesticides and nitrogen poisoning.

If a fish and game biologist is really concerned about saving the resources he works with, this book is a must in his library and as a guide to what actions he must take in life to slow down the extinction of many species including man himself.—*Ted Wooster.*

The Marine Mammals of the North-western Coast of North America and the American Whale Fishery

By Charles M. Scammon; Manessier Publishing Company, Riverside, California, 1969; 319 p., illustrated. $29.00.

Long a collectors item, this classic of the literature on marine mammals is now available in a beautiful facsimile edition. First published in 1874, Scammon's book still remains a standard reference.

Scammon, with little schooling, was a remarkable observer and a consummate artist. In words and drawings, he captured with skill and beauty his mammalian subjects, from the 100 ft sulphurbottom (the whalers name for blue whale), the largest mammal which has ever lived, to the porpoise and sea otter. His drawings and descriptions of the hazardous occupation of whaling are of a spine-tingling quality. His whaling tales are as hard to put down as a good novel.

Young William Healey Dall, only 19 at the time, was stationed on Scammon's flagship as acting lieutenant on two trips to Alaska. Already a fine naturalist, Dall, later to reach eminence in his field, added kindling to Scammon's already awakened interest in whales and seals, and probably helped inspire Scammon to his eventual writing of Marine Mammals. Dall called it the most important contribution to the life history of these animals.

In this year of heightened interest in the environment and conservation, Captain Scammon's description of the wholesale slaughter of whales and seals around the world is particularly timely.

Cambell Grant, detailing Scammon's biography in his introduction, brings out the little known facts of Scammon's contributions in the success of scientific exploration of Alaska and the important part he had in the plans to lay a cable across the Bering Sea between Siberia and Russian America.

Victor B. Scheffer says of the whale in his Year of the Whale, "Moving through a dim dark, cool, watery world of its own, the whale is timeless and ancient; part of our common heritage and yet remote, awful, prowling the ocean floor a half-mile down under the guidance of powers and senses we are only beginning to grasp." Charles Scammon brings these great animals to the surface for us to see and admire.

At a cost of $29.00 the purchase of this book will probably mean a sacrifice to most biologists who buy it, however, it will make a rewarding addition on any bookshelf. Here, over and above its scientific value, is a fitting companion to Melville for the lover of the sea.—*John G. Carlisle, Jr.*

The Central Desert of Baja California: Demography and Ecology

By Homer Aschmann; Manessier Publishing Company, Riverside, California, 1967; XIX + 282 p., illustrated. $12.00.

This book is based on a doctoral dissertation; it is the result of 5 years of work, including two lengthy field trips in 1949 and use of the extensive resources of the Bancroft Library, Huntington Library, and the San Diego Presidio Museum.

Baja California once was inhabited by a large aboriginal population. Today few of these people live there; this is especially true in the central desert which is considered roughly as the area south of El Rosario and north of Comondu. The author describes, in some detail, the economy and social organization that enabled many Indians to wrest a living from this dry land, before they were "reduced" to Christianity.

In presenting his thesis, the author also discusses the physical character of the central desert including climate, vegetation, soil, and other resources; the Indians

and their ecology and their contact with Europeans; and finally, the decline of the Indians and its various causes.

The section concerned with Indian ecology (about $\frac{1}{3}$ of the book) will especially interest those who love the desert, because it reveals how primitive people were able to live there.—*Harold B. Clemens.*

Lower California and Its Natural Resources

By Edward W. Nelson; Manessier Publishing Co., Riverside, California, 1966; XVI + 194 p., illustrations and maps. $12.50.

This is Volume XVI; the Memoirs of the National Academy of Sciences. First published nearly 50 years ago, this classic has been out of print for a long time. However, because of its importance to scientists, students, and others interested in Lower California it has been reprinted in its entirety. In addition an introduction has been included, along with general biological information about the author who was former Chief of the U.S. Biological Survey.

In the early 1900's, personnel of the Biological Survey were engaged in detailed studies concerning the distribution of animal life and environmental relations, in the arid regions of the United States. It soon became apparent that similar information was needed about Lower California. Reliable data, however, was difficult to get so it was decided that the Biological Survey should undertake a reconnaissance of the peninsula.

Under the direction of E. W. Nelson, an expedition was started in March 1905 and ended in February 1906. It extended the entire length of lower California and crossed it eight times from coast to coast. The results are set forth in this volume.

The first part, about 35 pages, is devoted to a daily account of the expedition. It includes a general description of the country and the plants and animals that were encountered. The second part, about 59 pages, describes in more detail the mountains, plains and valleys, surface and underground water resources, and the climate of the peninsula. In the third part, about 31 pages, the author presents a general discussion of the plants and animals noted during the expedition; then he divides Lower California into four major life zones (Arid Tropical, Lower Sonoran, Upper Sonoran, and Transition) and provides details about the plants, animals, and the environment in each zone. In the fourth section, about 8 pages, there is a brief discussion of the natural resources and the agriculture of Lower California. The fifth section, about 6 pages, is a brief summary of other significant expeditions into Lower California beginning with F. Deppe in 1837 and ending in 1911 with an expedition by the American Museum of Natural History. The final portion of the volume is an excellent, 25-page bibliography of Lower California.—*Harold B. Clemens.*

A Field Guide to the Insects of America North of Mexico

By Donald J. Borror and Richard W. White; Houghton Mifflin Company, Boston, Mass., 1970; 404 p., illustrated. $5.95.

A Field Guide to the Insects of America North of Mexico is the 19th book in the growing list of field guides edited by Roger Tory Peterson. It is typical of the other guides in that the "Peterson System" of pictured keys with diagnostic arrows pointing out identifying characteristics is used. This system seems to work especially well with insects since the structural details of insects may be more definitive than the field marks of larger animals.

Introductory chapters on the collection and preservation of insects, working with living insects, the structure of insects, the growth and development of insects, and the classifying and naming of insects serve as a good introduction to the field of entomology. The systematic chapters discuss each order as to identification, similar orders, immature stages, habits, importance, classification, and number of species. Especially good are full colour plates illustrating the Odonata, Orthoptera, Hemiptera, Homoptera, Coleoptera, Lepidoptera, Diptera, and Hymenoptera.

If any criticism can be made of this book it must be of the light treatment that the immature stages of insects receive. Immature stages are very briefly described in the general discussion of each order but only the adults are drawn. Many insects undergo radical changes in appearance and habit during their life cycle and may not be identifiable with the adult. More extensive treatment of this subject would have made this book more valuable than it already is.

In spite of this shortcoming *A Field Guide to the Insects of America North of Mexico* is an excellent guide to some 579 different families of insects. The amateur

naturalist or beginning entomology student will find it a valuable addition to his library.—*Ernest W. Lesh, Jr.*

Home Is the Desert

By Ann Woodin, The MacMillan Company, New York, New York, 1970; 247 p., illustrated. $2.95 paperback.

This book, written in a light yet philosophical tone, deals primarily with the flora, fauna and geology of the Arizona desert. Mrs. Woodin, the erudite wife of a herpetologist, describes features of this environment as it relates to the raising of her young family.

In the course of her book she recounts many humorous and delightful experiences with the wildlife of the area. Interspersed among these accounts, she delivers some pointed and perceptive conservation messages regarding the impact of man's activities on his world, and some fascinating details in the life histories of desert inhabitants. Her account of a float trip down the Colorado River prior to completion of Glen Canyon Dam and inundation of the area is a moving description of man's effort on nature's works in the name of progress.

This book's interesting mixture of ecology, nature study and philosophy makes worth while reading for anyone interested in our natural resources.—*James Holven.*

Wyoming Fishes (Third Edition)

By George T. Baxter and James R. Simon; Bulletin No. 4, Wyoming Game and Fish Department, Cheyenne, Wyoming; 168 p., illustrated. $3.00 paper.

The third edition of this paperback book has been completely revised by the senior author. Based on a recent survey of Wyoming waters, the book discusses 78 species, including native, introduced, rare and endangered, and possibly extinct species. The scientific names of all species have been changed to conform with *A List of Common and Scientific Names of the Fishes From the United States and Canada*, second edition, special publication No. 2, American Fisheries Society. Distribution maps have been added for 44 species.

The format of the book is logical and clear. There is a section entitled "General Notes on Fishes", which very briefly discusses classification, scale formation, external anatomy, and physiology. A section on "Physiography and Hydrography of Wyoming" discusses the major drainages, and includes a map showing their location.

Keys are included for identification to species. Information for each species includes a photograph, a distribution map (except for widely transplanted game species), a description, life history information, current Wyoming hook and line records, and an explanation of the scientific name. A glossary is included.

This is an excellent little book, well worth $3 to any fisherman, conservationist, or beginning fisheries student who wishes to be better informed.—*Kenneth A. Hashagen, Jr.*

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